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Understanding the Relationship between Performance Characteristics, Shot Selection and Decision-Making in the Game of Tennis

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UNDERSTANDING THE RELATIONSHIP BETWEEN PERFORMANCE
CHARACTERISTICS, SHOT SELECTION AND DECISION-MAKING IN THE
GAME OF TENNIS

A Dissertation
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy
Industrial Engineering

by
Dotan Israel Shvorin
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Accepted by:
Dr. Kevin Taaffe, Committee Chair
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Abstract

In order to improve tennis player performance, we first need to investigate the features of performance that define a tennis player. This research begins with a focus on understanding how performance errors occur in the game. Over a span of two years, data were collected and analyzed in order to demonstrate the impact of various performance characteristics on the player's capability. The outcome of this work was twofold. The research has been employed by the Clemson University tennis program to design improved training drills. The research has also been used to form a baseline for making decisions at the management level.

When managing a tennis program for a Division 1 school such as Clemson, recruiting is achieving higher levels of success. Since recruiting depends heavily on a player's performance characteristics evaluation, expanding the gained knowledge in this area seems a natural development. Concluding a preliminary review of recruiting processes beyond the sport of tennis, it became clear that a gap exists in evaluating the decision-making nature of the player. While some players may present a more strategic style, others may lean toward a tactical mind set, and some will be able to adapt to both when required. In order to fulfill this gap, a theoretical framework is presented in this work, that bridges between performance characteristics and decision making. Utilizing certain situations that the player will face in in the game, the player's decision-making style can be evaluated when all the alternatives have been considered and compared. The best response to a scenario will vary between recruiters depending on the decision making profile they desire in a potential recruit. The suggested framework has been tested in a small scale case study with the Clemson Club Tennis team. The results demonstrate certain differences between the players' decision-making styles and was used as an exploratory tool to understand a player's mental or analytical reaction (as opposed to physical reaction) to the game situation.

With knowledge gained from exploring both performance characteristics and decision-making abilities, a logical progression was to assess how these components of a player's game would work in practice. This knowledge was put to the test in the final research chapter - identifying the impact of fatigue in a target

selection game and improving player performance (i.e., scoring on the targets) via informed decision making based on a player's physical state. In this section, a tennis game and a computer simulation model were used in order to illustrate to tennis players how to make better decisions when considering their performance under fatigue. While the players are making decisions based on their perceived ability to hit the target, their biodata is captured to identify trends of heart rate, stress levels, shot acceleration, and skin temperature over time. In addition, each player's shot selection and success rate were recorded to identify patterns in their reasoning. As heart rate was the main biodata identified as significant, a simulation model embedding a player's heart rate data, as well as his or her success rate in hitting each target and target selection decisions, in order to test better shot selection or decision making to improve overall score.

The contribution of this research could support competitive college tennis programs with specific applications to practice, training and recruiting.

Dedication

I dedicate this research to the people who made it possible for me to develop this area of interest. To my family, who have provided love and support when faced with life challenges. To my friends, who provided valuable insights and great times together. To my mentors, who shaped my capabilities and patiently waited to see their hard work come to fruition. To my colleges, who work with me in many settings as we explore new research areas. Lastly, to my students, who provided research ideas, thoughts and emotions that have shaped my point of view. Without these people, I could not have reach this stage in my life, thus I humbly cherish their contribution to every aspect in this work.

Acknowledgments

Many people are involve in this research and contribute in many aspects. The industrial engineering department has demonstrated its support in providing recognition to our efforts. With the help of Dr. Smith, department chair, we have been given a laboratory to conduct our experiments as well as IT support from Mr. Clark. This has been a great encouragement for our research efforts.

The creative inquiry (CI) program have been our main financial support as an internally funded research initiative. Altogether, this research expenditures totaled to \$20,000 worth of equipment and software. The program promotes the collaboration of undergraduate students into research endeavors with faculty and graduate students. It has been my pleasure to lead such a research group when focusing on this research area. The Watt's family innovation center has provided us a unique learning environment where our technology could be optimized. The supporting efforts of Dr. Barbara Speziale, are tremendous in promoting our research endeavors. Mr. Burns and Mrs. Lockhart provided endless technical support in operating the advance technological capabilities of the innovation center, to accommodate our research activities.

Specialist that have contribute beyond the call of duty have conducted various type of activities with our research group. Dr. Stewart, former director of the student disability center in Clemson university, provided workshops as well as research guides to our research group. She has been an incredible source of inspiration in utilizing our research to investigate disability conditioning. In the same note, Dr. Ramsay, director of the Marcus Autism Center in Emory university, has provided us with a unique look on running longitude research as well as insight on laboratory settings. Miss. Norungolo, a specialist in student disability at Clemson university, has work with us in developing our understanding of attention deficit / hyper active (ADHD) disorder. Her efforts have led to a collaboration with the disability center as well as harness the support of the Dr. Griffin, dean of undergraduate studies. These specialist have shaped the vibrant atmosphere of our research group and promoted our ideas with a methodological approach and guides.

Undergraduate students have been a major part of this research as they contribute to the experiments

design and execution. The research have utilized over 70 undergraduate students, who were involved in multiple aspects and performed a variety of activities to explore this research area in its broad perspective. They have been the back bone of this research and with out their participation, this research could not have developed to this stage.

Last but not least, Dr. Kevin Taaffe has been my mentor for the last six years. I have learned so much from him when accustoming to Clemson culture, overcoming my learning disabilities, planning and running an internally funded research program, teaching simulation classes, and engineering the operating room of the future (RIPCHD.OR, AHRQ). Dr. Taaffe has invested efforts in developing my skills and I can't learn enough from him, as we overcome many challenges together.

These people have been instrumental in my development as a researcher and I am looking forward to continue our relationships beyond Clemson university.

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Chapter 1

Introduction

1.1 Background

This research was born from the integration of engineering tools into player performance as a small project for the Clemson tennis team program. As a researcher and a coach, I was able to collect data on each player, creating a rich data set from video recording to match statistics. Analyzing this data, I identified initial relationships that could directly affect their training structure. Upon implementation of short term improvement features with positive outcomes, it became evident that additional research was needed if changes to the program were to be achieved.

A request from the tennis program management level (director Bill D’Andrea) pushed me to pursue a robust method that would expose a variety of features that affect player performance. It was critical that we involve several individual’s such as the management director, the tennis coaches, the physical trainers, the academic supervisor, the nutritionist, and the players on the team. This research began with a process improvement attitude from all specialists involved, and excitement was beginning to foster motivation among all participants. The research insights pointed towards evidence-based program approach. As a result, a ”high performance team” management structure was established in January 2014. In this structure, each trainer contributed his players’ records into one data set that allowed the management team to capture the team status and make decisions based on inputs from each specialist involved.

Upon this successful experience in working together with various sports management specialists, trainers and coaches, the head coach of the tennis program was really determined to improve their recruiting process. We had many conversations on how to capture a broader picture of player performance; however the

recruiting process is not well suited for this kind of approach. I decided to further investigate the recruiting process by leading multiple Creative Inquiry teams (comprised of Clemson undergraduate students) and began working with more sports management specialists from the Clemson athletic program.

Working with support from the students, we studied the recruiting process across different types of sports. Focusing on the decision-making evaluation, I utilized decision trees and game theory to quantify the available choices for a player in a game, resulting in a pool of questions with answers that can be easily ranked. Furthermore, the answers rank will help to identify if the decision-making style of the player fits the coach expectation for that position in the game.

In my final phase of this research project I began to explore how performance characteristics impact decision-making. Fatigue is perhaps an easy concept to grasp, but its impact on decision-making has not been fully explored. Specifically in tennis, it is demonstrated by researchers that fatigue reduces the level of the player performance due to physiological, psychological and emotional implications (Ferranti et al. (2001), Davey et al. (2002), Lyons et al. (2013), Pearcey et al. (2015), Bachasson et al (2016), and Bouaziz et al. (2016) just to name a few). The work that is presented in this dissertation (specifically Chapter 4), aims to identify how fatigue should be handled in a target selection game. Since fatigue degrade the player performance (this is shown in the chapter analysis as well as in the literature), at a certain point the player will have to adapt his decisions to accommodate for that change. In order to explore this logic, a drill is designed to capture the way that the player will adapt when he gets tired and as he recuperates. In this research, I tested the effect of fatigue on several players, and I explain the patterns behind individual shot selection and how performance (and ultimately success in shot selection) can be improved.

1.2 Motivation

My research contains an environment that I have pursued professionally as a junior tennis player. Representing the state of Israel at the Maccabi games, playing in the Spanish Federation League, and participating in various national competitions have provided me a firm background in the sport of tennis. At the age of 15 I was offered a scholarship from the Sergi Bruguera academy in Barcelona but could not pursue that dream as my family could not financially support it. From this phase in my life, I carried a feeling of a missed opportunity to fulfill my dream of becoming a professional player. Through the years of my life devoting to this sport I began coaching players of all ages, from little toddlers who barely can hold a racket to senior players who overcome various difficulties in order to play the game. By the age of 18, I gained experience from training, learning, teaching and performing.

Enlisting to the military is mandatory in Israel, and I volunteered to serve in a special forces unit called Maglan. In this unit, cadets train for two years before completing their required level of proficiency, ranging from hand to hand combat to missile guidance systems. Coming from a very strict program of performance in the tennis world, the military program pushed performance to a whole new level. In the tennis world, you are independent but in the military you are a part of a team. In the tennis world you engage in the game when you are in perfect conditions - rested, energize, focused and prepared. However in the military you train to perform at your best in the worst of conditions, such as when you are tired, weak, hungry, exhausted, cold or hot, injured or hurt, as well as under great uncertainty. From these experiences, and my resulting higher level of self control and situational awareness, my tennis game has improved significantly as I experience new levels of physical, emotional and mental capability.

A month before my service time was supposed to end, I was severely injured in the second Lebanon War. The war left me physically disabled as well as demonstrating post traumatic stress disorder (PTSD) behavior. The rehabilitation facility had just received a new interactive game for patients to improve their physical training as they interact with a big screen. In an unthinkable coincidence, the chosen game for the training was tennis. I had controllers that followed my striking motion and transferred it to the avatar in the game, as if it was me who hit the ball to the second player in the game. I still hold the highest score in the facility, yet to be broken.

Coming to Clemson University I naturally was drawn to the tennis courts. I immediately got an offer to participate as a volunteer coach for the women's tennis team. This position lead to some of the ideas presented in this research.

Tennis has always been a big part of my life and miraculously finds me at every turn that I take. I love everything about the game, from the equipment, to the social relationships and the challenges that the game presents. It is with great pleasure that I present this research into how individuals can achieve more than what their physical abilities would imply.

1.3 Structure

The work presented is organized in a way that allows the reader to see the natural progression of how the research was conducted, first through an exploration into the connections between personal characteristics and performance, then through a model that quantifies decision-making while accounting for opponent characteristics, and finally through an examination of a specific performance characteristic – fatigue. As we zoom into our application outcome, the logical development is illustrated. The breakdown of

the dissertation is as follows:

- Chapter two presents a process improvement approach that investigated the cause and effect relationship of tennis player performance. Implementing a quality engineering methodology with the Clemson women's tennis team program resulted in a restructuring scheme for managing the program.
- In chapter three, a theoretical framework for evaluating the decision-making nature of a player is developed and tested in a small case study. More work in this area will be pursued outside of the dissertation scope.
- The fourth chapter in this research binds the two former chapters conceptual work, as it investigate the relationship between specific performance characteristic (i.e., fatigue) and the decision-making nature of the player in a target selection game.

1.4 Research Questions

The research questions presented here show the logical progression of the work over time. In chapter two, the following research questions guided the collaborated work with the women's tennis program.

1. What are the tennis player characteristics of performance?
2. How do these characteristics impact player performance?

Working to answer these questions exposed the complexity of the player performance and aided with the improvement processes that occur in the athletic department. One of the following issues of process improvement for the athletic program was recruiting, thus chapter three is guided by the following three research questions. The first question guided the literature review in the chapter, the second question generated a theoretical framework which is presented, and the final question was explored in a case study at the end of the chapter.

1. What are the gaps in the recruiting process in different sports?
2. What solutions can be develop in order to close the gaps illustrated in the research?
3. How can we make initial examination of the solution framework?

Isolating one specific performance characteristics impact on decision-making, chapter four present how fatigue influence the player performance when guided by the following questions.

1. How fatigue impacts tennis player performance in a target selection game?
2. How can player decision-making be improved when considering the impact of fatigue over time?

The first question drove the design of the drill and the game that is presented in the chapter and the second question promoted a problem solving modeling using simulation. The answers to these questions are illustrated in the chapters but summarized in the conclusion section of the dissertation.

Chapter 2

Improving Tennis Player Performance Using System Development Interpretations Methodology

2.1 Abstract

This research demonstrates a unique analytical approach to improving a player's performance in the game of tennis. We introduce a system development interpretations (SDI) methodology for associating player characteristics and factors in a hierarchical structure. We then show how this tool is applied in a human performance environment such as tennis. This approach was developed as a multidisciplinary quality tool for process improvement that identifies factor dependencies and depicts their impact on the resulting player performance. From the implementation of the SDI methodology, the research was able to define the tennis player's difficulties and it has allowed the researchers to build an entire team profile of the Clemson University tennis program as well as to introduce important conceptual foundations in this field.

2.2 Introduction

In order to achieve a high performance level in the tennis match, the tennis player must understand the relationship between different factors that affect his level of performance. Those factors can be divided

into two main concentrations: internal and external. The internal factors could be characterised as internal inputs to our decision-making process such as stroke technique (Landlinger et al., 2012; Pugh et al., 2003), body resources management (Hofe and Fery, 1991; Mead and Drowarzk, 1997) and emotional intensity (Fernandez et al., 2006; Gondola and Wughalter, 1991; Hornery et al., 2007). The external factors could be characterised as external inputs to our decision-making process such as court conditions, weather conditions and the opponent game type (George, 1973; Howard, 1980; ODonoghue and Ingram, 2001). The key to achieving a high level of performance lies within the ability to translate the external inputs and the internal inputs into a winning game plan. The process of developing a game plan is not an open loop process but rather a closed one. A game plan could change at any time due to a change in the internal or external inputs (Weinberg et al., 1980; Whitaker-Bleuler, 1982). A winning game plan can be considered similar in its process to quality methodologies seen in production systems. However, with human performance, system quality is more difficult to establish. When we consider a production process, there are many tools that are used to increase the quality of the process, the capacity of the production line and the efficiency of the machines. Those tools can quantify data from the production process, thus allowing mathematical or statistical methods to be employed. This research is attempting to create the same quality approach which is embedded in the industry, to increase the tennis player's performance level. We have used the system development interpretations (SDI) methodology (Shvorin, 2011) which was developed to improve the plastic injection manufacturing process. The SDI methodology is enabling us to identify the ways in which factors in manufacturing are related. In using the SDI method in the plastic injection manufacturing setting better machine tolerances were defined which ultimately lead to manufacturing error reduction and material savings. Quality control protocols for material handling and work force quality assurance proceedings were created to ensure that a high level of performance was established. Furthermore, key performance indicators (KPI) were created in order to better schedule maintenance applications and to increase production efficiency. However, we note that the implementation of the SDI methodology on human performance is not a simple plug and play methodology; it requires an understanding of how to define human behavior within an engineering approach. With the SDI method a team profile of performance measurements was developed. With the help of the tennis program coaches, behavior characteristics were identified and solution applications were implemented. An in-depth literature review will provide information about the history of the tennis game development as well as a relevant range of the game's analysis methodologies. Next we will discuss the SDI methodology development and its implementation on the tennis game, with the creation of the tennis team profile. After analyzing the SDI methodology outcomes, we will open a discussion on the research findings

and conclude the future possibilities for advance research

2.3 Literature review

The tennis game development takes us back to the 12th century as a part of a rivalry between two opponents. In those times, games were developed to test one person's ability to overcome an opponent. The outcome of the game or test was heavily considered in the ability to maintain a certain status, class and honor among the relevant societies. The name of the game refers to the word *tenez* in French which means receive a key feature of the actual game. Over the last 100 years, the game has advanced in many ways (from equipment and venues to the ability of the players) (Antnez et al., 2012). In particular, not only were the physical characteristics of the player advancing but the mental approach to the game was also advancing. The need for the player to be better, stronger, faster and more mentally prepared has opened the sport to the research of how to attain these qualities to achieve the desired outcome. Since the game was orchestrated by the upper class, it was driven from knowledge, which was used to overcome the opponent. The rivalry of two opponents in the game can be defined from a wide range of behavioral characteristics of each player such as the ability to perform, the techniques employed to execute a course of action and other strategies and tactics. According to del Villar et al. (2007), there is a substantial difference between the levels of a player's performance that emerge from his or her decision-making capabilities. Experienced players consider more characteristics in their decision-making process and have a better ability to select the right approach in a certain scenario in order to overcome their opponent. This line of research was first explored by Nielsen and McPherson (2001). They defined three components in the player's performance characteristics that could signify the differences between the levels of a player: control skill, response selection skills and response execution. The first component measures the player's ability to technically perform a certain stroke or movement in a given situation. It refers to the player's coordination, perception of space and his body biomechanics potential. The second component refers to the player's ability to select the suitable approach from a wide variety of possibilities in order to overcome his opponent. This component describes strategic and tactical choices that a player makes based on his interpretation of the game. The final component measures the outcome implications from the selected approach execution. Those performance measurements proved themselves as a way to evaluate the level of a player and to identify his weaknesses as well as his strengths. Since this research was based on observation characteristics only, it did not address the players state of mind. In research by Gonzalez et al. (2012) a more rigorous approach was taken based on the same method except that it now included an interview application during the player's match. They were able to classify a wider

range of features to represent the player's level of performance. Lames (2006) extended this point of view by adding time perspective and momentum building aspects to the performance and response characteristics of a player, which was similar to that discussed in del Villar et al. (2007). Beyond the somewhat constant skills and abilities of an athlete, tennis contains a complex system of cause and effect interactions, which can result in a significant change in the actual performance level of the player. Performance level changes are time dependent, when fatigue takes its toll for example or momentum dependent when a player wins a few points in a row. The dynamic aspect creates numerous decision possibilities over time. As one response is perfect for one moment in time it could be devastating for another. For example, the player can be continuously searching for a successful strategic and tactic behavior based on the actual score or based on the actions of the opponent. One analysis method used in Lames (2006) is the relative phase concept. This analysis deals with the special features of the player with respect to his court positioning as a response to the opponent's reaction. A relative phase means that the player's court movements are relatively similar to one another. The relative phase is balanced when both of the players are in a proper position to hit the ball. As the point plays out, the balance of the relative phase begins to be unstable. The unbalanced phase ultimately results a point won or lost. This analysis was driven from signal detection theory as it allows calculating continuous relative phase, which is mandatory because we have comparatively few strokes in the rally. This research allowed considering three more characteristics in addition to the player's component descriptions such as time dependence, momentum build up and court positioning functionality. Palut and Zanone (2005) further defined the relative phase concept as one of two relationships: In-phase or out- phase. They also addressed the transitions between them as another indicator for court positioning characteristics. The phases mentioned above simply tend to define the relationship between attacking and defending. When an attack is made, we can expect a phase out which means that the balance of the relative phase is about to be broken. If a defensive course of action is taken then we can expect a phase in which means that the relative balance is about to be restored. Relative phase research provided further interpretation for the player court positioning characteristics in response to the executable course of action. One of the most dominating factors in the player's performance received its respectable attention in Akpinar et al. (2012). Their research dealt with anticipation abilities in racket sports. This research method of analysis used a Basin anticipation timer, a LED bulb runway that creates the illusion of motion from the way that it operates. It is by adjusting the speed and stopping distance of the flashing red lights that the level of anticipation could be evaluated. The anticipation ability serves as one of the most critical attributes to the tennis player as it demonstrates prediction abilities (Triolet et al., 2013; Williams et al., 2002). Once a player predicts the ball

interception location, opponent movement orientation and a decision execution outcome, he has more time to prepare, adjust and select the best way to overcome his opponent. A shortage of this ability will result in a disadvantage which will immediately affect the player's level of performance. This concept extends the research found in Lames (2006) and it provides one feature that could make a huge difference in the player performance capabilities. Beyond the internal characteristics of a player, the performance level of a player can be affected by external characteristics of the game such as the surface of the court, weather conditions and equipment. ODonoghue and Ingram (2001) and Fernandez et al. (2008) addressed the court surface attributes and how they affect the interaction between the players. There are four types of tennis court surfaces, each one with distinct features.

The grass court poses a low level of friction, thus the ball slides on the surface instead of bouncing. For the same reason, the player's ability to accelerate and change direction decreases as well. In the red clay court, the characteristics are reciprocal to those in grass because clay poses the highest friction properties. The last two courts are the mitigation courts between the two extremes. The hard court and the light clay (blue, green) court demonstrate more friction than grass but less friction than heavy clay (red clay). These surfaces affect stroke variety selection and a player's execution abilities and as mentioned earlier, each change requires a new game plan that affects the player's performance level. In the last section of the literature review, we focus on the statistical characteristics of player decisions and performance over time. Research by Klaassen and Magnus (2001) tested individual game points in relation to each other from a statistical point of view. The research revealed that points are neither independent nor identically distributed. They found that the outcome and characteristics of the previous point affect the current point and each point has a slim chance of being the same as the previous point. This concept proves that the game analysis could not be established from isolated characteristics but rather a chain of events. This means that the characteristics of each player affect the other and result in (time-dependent) performance ability (Wong and Zigarovich, 2007). Over the past three decades, there has been a wide variety of research conducted on tennis player performance, which range from specific player's technical assessments (Stepien et al., 2011) to a unique behavior analysis (Rees et al., 2000). This review raises a need for a unique analysis platform that could establish the connection between the player's characteristics with the necessary statistical reliance in order to understand the path for performance improvement. In the next section, we will engage in a multidisciplinary quality approach in order to understand the player's characteristics and their relation to his ability to win or lose a point (i.e., his performance level).

2.4 SDI methodology development

Quality is a well-established discipline in the engineering management profession (Hopp and Spearman, 2008). However, it took 50 years before it gained prominence as a means of process improvement in industry. It was during the 1970s and 1980s when Japanese companies gained a significant advantage over their competitors by implementing a just in time (JIT) methodology in their manufacturing processes. Other countries eventually recognized the improvements being made in Japan and began developing their own quality programs. In particular, it was not until the 1980s that US industry really took notice of the strategic potential of the quality approach. More recently, lean manufacturing and Six Sigma continue to be ubiquitous programs for process and quality improvement in many industries today. The main goal of quality improvement is to reduce process randomness, process variability and increase the overall process performance level. Our research methodology takes another step in the development of a quality approach by examining the characteristics of the variability and how they may contribute differently to the randomness above the process mean value or below the process mean value. Specifically, SDI analysis takes the next step in variability reduction by asking when and where variability reduction needs to occur. We can support this aspect of variability reduction by including defect analysis consideration into tolerance optimization. If we can assume that there is an optimum point of operation, then tolerance definition tells us that we can have a certain allowable variability around this optimum point and the reduction of variability may be different in each direction from the optimum point (Shvorin, 2011). Consider the following analogy. Assume that our goal is to find the balancing point of a beam when two people are sitting on opposite ends of the beam. Based on the weight difference of the two people, the balancing point will shift towards the heavier person until a balance can be established. This may cause more variability to exist on one side of the process, leading to a significant portion of outcomes that are outside the acceptable tolerance limits. If we cannot change the balancing point we need to reduce the distance from the heavier side to the optimum point in order to achieve a balanced system. In order to achieve balance in the system, we need to figure out which side is heavier (creates more defect in the system) when we consider variability definitions. If we want to develop those concepts we need to take a step back and look at the cumulative effect of the deviations on the system. Once we can define the cumulative effects we will be able to characterize the variability behavior and adapt our tolerance definitions to increase our system performance capabilities. In order to achieve this point of view, the SDI analysis method was developed. The first application of this methodology was to improve a polymer injection manufacturing process. In the polymer production environment, the relationships between the process materials and the time window for their reaction were a key ingredient in the quality of

the product. By identifying the material effects to one another, while considering a certain time reference, the SDI method was able to tune the manufacturing process to achieve a higher level of performance. The research was triggered when a leading irrigation equipment manufacturer was facing increased production levels while managing it with a reduced workforce. This led to a rise in the defect percentage. By using the SDI methodology, they were able to understand how those defects were created. Then, new machine tolerances were established and the defect percentage was reduced. SDI combines the field research knowledge with information gained from experience to create a database of relational information. In order to create this database, the application of SDI (i.e., the SDI algorithm) is outlined below:

1. Map the defects of the process and define the relative weight for each defect characteristic (Pareto chart)
2. Determine the causes for each defect while integrating process capabilities and work force experience
3. two values (if appropriate) for which the cause could be defined (with respect to some characteristic or action of a defect):

Upper deviation from the optimum response within some tolerance

lower deviation from the optimum response within some tolerance

4. Provide a relative weight to the causes of the defect to maintain the relative influence of each cause on the process
5. Calculate the cumulative effect of each cause for creating defects in the system
6. Adjust the cause's tolerance when considering the cumulative effect on the system
7. Create protocols for the new working environment

The second part of the SDI methodology is the ability to map the connections that it establishes between dimensions of cause and effect. When applying the algorithm for the first time, we expose the first order connections. Depending on the environment, the algorithm can be applied a second or third time (to reveal second or third order indirect connections). These additional applications provide a more complete, dimensional relationship (or branch) between the source and its outcome. Once we map the dimensional connection chain from one point to another, we can detect significant pathways to achieve improved performance. In this manner there are two main points that characterize this process:

- It is possible to achieve a multiplicative (as opposed to a linear) improvement in system performance based on making a small (but significant) change in the source
- the difficulty of imposing a change is increasing with further iterations of the SDI algorithm

In the next section we will use this approach to analyze the Clemson tennis team in order to improve their performance level. First, we will define the analytical approach and then we will explain the research findings.

2.5 SDI methodology implementation with the Clemson tennis program

Using the SDI methodology requires that we identify connections between factors that affect the performance level. One contributing area of research in tennis is negotiation theory. Similar to tennis where two opponents are battling to win the match, in negotiation, the two sides are trying to achieve the best deal for each other. The foundations of negotiation theory are decision analysis, behavioral decision-making, game theory and negotiation analysis (Alfredson, 2008; Wall, 1985). Negotiation theory provides three concepts to characterize the interaction between two sides.

- The first concept that is integrated in to the SDI methodology from the negotiation analysis is strategy definition. Strategy can be only one of two things: uncompromised (attack) or compromised (defend). Similar in the conscious choice for deciding what to do (strategy), player first needs to decide whether to attack his opponent or to defend himself from his opponent's attack.
- The second concept inherited from negotiation analysis is tactical definition which tells us how to perform the chosen strategy. Similar in the tennis game, the player needs to decide how he is going to execute his attack.
- The third concept which is integrated here from negotiation analysis as behavioral decision-making is addressed in this research as a mental mode description. This concept forces the operator to understand why he chose this mode of operation. In tennis, this is a main feature of consideration because it points out to the player's decision-making triggers.

In order to begin the SDI algorithmic approach we have to define a main concept that will guide us in the analysis process. In the SDI method we are identifying defects but what are defects in the tennis

player's game. A defect in the tennis player game by definition in this research is a wrong decision-making in the player's game. A wrong decision does not necessarily mean that the player lost the point; it is a statistical consideration of the long run probabilities that he will lose that point according to his decision. For example, player A performs a touch stroke and player B did not pass the ball over the net such that player A won the point. However, if this scenario is played ten times, player A would win the point only once while player B would win the point nine times. If player A decides to perform a touch stroke against player B he statistically made a wrong decision. Next, we create an error list that characterizes errors based on all of the players on the team. In this stage the list is constructed from the knowledge of the tennis game and the experience learned from the team performance. With the implementation of the SDI method on the Clemson tennis team, over 50 observations of singles and doubles matches were gathered and analyzed by the coaches. Some of the matches were evaluated live and some were evaluated through a video recording system. As mentioned earlier, the definitions of the error list were made based on expert opinion from the input of the coaching staff. In Table 2.1, we see the result of the error list creation. This list characterizes the team's cumulative profile, which can be used to develop a more purposeful training program for the team. The relative weight represents a Pareto distribution of the error list.

Table 2.1: Error list and relative weight

Error list	Relative weight
No point construction pattern from the game plan	45%
Follow up reaction misses	20%
Wrong stroke selection misses	15%
Degraded performance under pressure	10%
Misses of strokes outside of the hitting comfort zone	5%
Misses of back movement strokes	3%
Easy put away misses	1%
Low motivation misses	1%

Table 2.1 denotes eight errors (or defects in manufacturing terms) that are most common to the team's performance:

- this list we can see that 45% of the errors occur because there was no point construction pattern from the game plan. This error definition means that the players deviated from their game plan, thus making an error that led to a point for their opponent.
- The second error is a miss from a follow up reaction. Approximately 20% of the errors occur due to second- or third-move misses of the points construction application. As an example, a player hits a

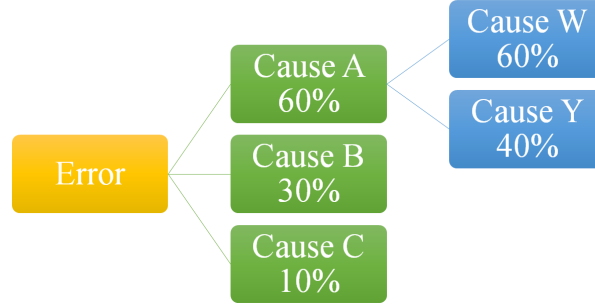
very powerful shot that forces their opponent to return a short ball. However, the player misses the next pressure shot and loses the point.

- The third error is when the players choose the wrong shot to execute. For example, after the opponent attacks, the player chooses to respond by attacking and loses control over the ball and, ultimately, loses the point.
- The fourth error is degraded performance under pressure which means that in critical moments of the game the player does not execute their chosen course of action as well as they would have done otherwise. Examples of such pressure situations are break points, tie breaker games, etc.
- The fifth item addresses the ability to react to a difficult challenge shot. For instance, a player loses the point due to failed shot execution from a difficult positioning.
- The sixth item refers to hitting the ball with a backward movement. This means that an error occurs when a player is moving backwards while trying to execute their shot selection.
- The last two items address those points that should not be missed and points where players do not possess the right attitude.

Once we defined our error list (defects) we can carry on with the analysis. The first group of factors are intuitively the first order connections to the decision-making process. We can define those factors when we examine what attributes can contribute to the creation of an error from the error list. We will get a list of factors that can be classified to the three concentrations: strategy, tactics and mental mode. The second order list is created when we ask the same questions (activating the SDI algorithm for the second time) but now we are examining what elements could contribute to the factors that caused the first order error list. We can continue in this same pattern in order to identify all factor relationships and dependencies. These connections and dimensions are critical because once they are defined their contributions will aggregate throughout the SDI algorithm. Consider Figure 2.1:

We see that this error has three first order causes (A, B, C) with two second order attributing causes (W, Y) that lead to cause A. We can also see that each cause has its own relative weight within the order level. The statistical attribution in this case is very clear and we can evaluate how a second order cause can indirectly affect the creation of this error. Once a path or relationship is defined, this research will be able to identify those relationships with the highest statistical effect on the players' decision-making, the players' performance level and the game training applications. We now introduce the three levels of connections that we will specify as part of the SDI algorithm:

Figure 2.1: SDI algorithm example



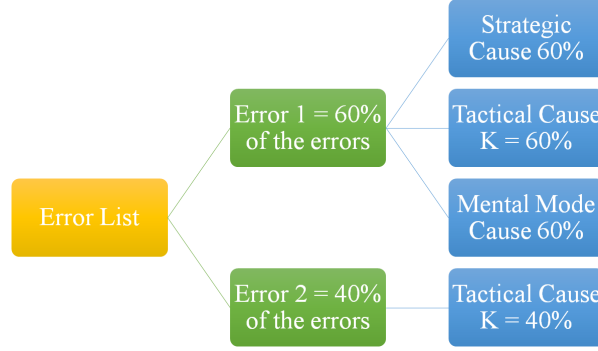
1. The first order connections reveal the direct connections. Any change in these characteristics will directly affect the performance level of the players, which would change the error list percentile attributes.
2. The second order connections will be characterized by indirect connections and an indirect effect on the player's performance level (e.g., a change in the second level will cause changes in the first level which will change the players' performance level directly). A change in this order level possesses the potential to affect the player's understanding of the game, thereby increasing his performance level beyond what can be done by focusing solely on the first order characteristics.
3. The third order connections address core values (or building blocks) and their connection to making an error. These relationships possess a greater potential for performance improvement because they contain the ability to change the player's game perception, situational awareness and behavior.

We propose that all errors can be classified as being caused by strategic, tactical and or mental mode failures. In order to classify characteristics as being of type strategy, tactics or mental mode, we adopt the following leading questions.

- What caused this error? (if a characteristic answers this question, then it is strategic)
- How was this error created? (if a characteristic answers this question, then it is tactical)
- Why was this error created? (if a characteristic answers this question, then it is mental mode)

From the first implementation of the SDI methodology, we received an error list and a list of causes to each error. We then aggregate the relative weight of an error on to its causes in order to determine the extent to which each cause affects the error list. For simplification purposes, consider the example in Figure 2.2:

Figure 2.2: SDI aggregating statistics method logic



Here we see that there are two errors in our list. We can see that one error is occurring 60% of the time while the other error occurs 40% of the time. There are three causes for the first error – one strategic cause (which explains what causes the error), one tactical cause (which explain how the error is occurring) and one mental mode cause (which explains why the error is occurring). There is a single tactical cause for the second error. In order to apply the statistical weighting (or effect) to our three classifications of strategic, tactical and mental mode, we apply the following logic:

$$Strategic_{weight} = \frac{\sum StrategicCause_i}{\sum StrategicCause_i + \sum TacticalCause_j + \sum MentalMode_k} = \frac{60}{60 + 100 + 60} = 27.3\% \quad (2.1)$$

$$Tactical_{weight} = \frac{\sum TacticalCause_j}{\sum StrategicCause_i + \sum TacticalCause_j + \sum MentalMode_k} = \frac{100}{60 + 100 + 60} = 45.4\% \quad (2.2)$$

$$MentalMode_{weight} = \frac{\sum MentalMode_k}{\sum StrategicCause_i + \sum TacticalCause_j + \sum MentalMode_k} = \frac{60}{60 + 100 + 60} = 27.3\% \quad (2.3)$$

In Table 2.2, we present first order relationship results from our actual case study. Using this same logic, we see that strategy (defined by three direct characteristics or traits) affects 47.5% of the error list. We also record the cumulative error effect of each characteristic. Identifying opponent strengths and weaknesses has a 19% effect from the strategic point of view, but this parameter affects 84% of the original error list in Table 2.1. This implies that these strategic characteristics are connected to many items in the error list and

the tasks affect each error in a different way. The second concentration of factors (i.e., tactical) affects 39% of the error list and it is also characterized by three direct characteristics or traits. The third concentration of factors (i.e., mental mode) affects 13.4% of the error list and it is characterized by three characteristics as well. With this structure in mind, we can now realize the most important elements of the direct connection for improved performance.

Table 2.2: First order relationships

Direct characteristic/trait	%	Cumulative error effect
Strategy 47.5%		
Identify opponent strengths and weaknesses	19%	84%
Classifying opponent game type	14%	59%
Comprehend and formulate a game plan	14%	62%
Tactics 39.1%		
Stroke adaptation	9%	39%
Court positioning	10%	45%
Point construction	20%	85%
Mental mode 13.4%		
Decreased level of physical ability	2%	9%
Decreased level of play	6%	24%
Error replications	6%	25%

From the first order relationships, we can identify two player characteristics that stand out: identifying strengths and weaknesses (strategy) and point construction (tactics). Both of these characteristics signify that most of the errors come from inappropriate decision-making (both at the macro and micro level). In order to understand the second level causes that affect the first level causes, we engage in the second iteration of the SDI method. We present the data in Table 2.3, where we can look at the micro effect of each classification (strategy, tactics and mental mode) and the macro effect that transcends to the first level. The second order relationship characteristics have the same statistical structure as the first order relationship database. The SDI method was used to determine how to aggregate the relative weight on to the second order causes.

The secondary causal relationships expose more parameters that take their toll in the performance considerations. However, different from Table 2.2, these relationships introduce the effect on errors based on both the over-use and under-use of any characteristic/trait. This is different than the 'yes/no' mentality of the first order characteristics where we evaluated whether or not a particular characteristic was present in a player's performance. For example, the player will make more inappropriate strategic errors when he does not sufficiently probe (i.e., experiment to evaluate and gain knowledge about the opponent capabilities) his opponent. If he does not probe his opponent and thus cannot identify the opponent's strengths and

Table 2.3: Second order relationships

Direct characteristic/trait	%	Cumulative error effect	
		High value/over use	Low value/under use
Strategy 47.5%			
Probing applications	11%	30%	70%
Stroke variety	14%	31%	87%
Self-awareness	11%	67%	47%
Clarity of thought	11%	33%	67%
Tactics 39.1%			
Reaction time	6%	40%	60%
Stroke power	6%	56%	16%
Stroke angle	8%	34%	80%
Stroke height level	10%	28%	98%
Stroke spin	9%	13%	88%
Mental mode 13.4%			
Confidence level	2%	54%	71%
Self-belief	3%	65%	91%
Fear intensity	2%	42%	64%
Temper implications	2%	37%	75%
Mental pressure	2%	77%	35%
Stroke motivation	2%	58%	42%

weaknesses, then he will not be able to build a game plan accordingly. On the other hand, if the player over probes his opponent, this could result in confusion and difficulty in deciding on a specific game plan. Moreover, probing takes time, during which the player's game plan has not really been set yet. This will lead to the errors mentioned in Table 2.1. We summarize findings based on the subjective interpretation of the coaching staff where the second-level SDI methodology data was applied.

- The strategic findings show that that the players (and team as a whole) should increase their probing abilities, stroke variety and clarity of thought (i.e., separating relevant information from irrelevant information). Reducing their self-awareness mainly implies that the player will increase his focus on the opponent.
- The tactical findings point out that the players need to increase their stroke angle, height and spin in order to improve their performance. In this case, we often see that the team uses more power than they are able to control which leads to unforced errors.
- The mental mode findings indicate that the team needs to have more psychological preparation to deal with confidence, self-belief and temper control in order to improve their performance level.

Finally, Table 2.4 allows examination of the team profile at a deeper level of consciousness. This is an area where these characteristics can be analyzed and tested in training sessions. The last iteration

of the SDI method, a key contribution of this research, defines how more fundamental personality traits and characteristics (as opposed to player skill and skill effectiveness from Tables 2 and 3) translate into performance and errors. These characteristics and traits can also be defined as the building blocks of our behavior. The most relevant characteristics to the game of tennis have been included in Table 2.4. By adjusting the intensity of any of these characteristics, a unique personality forms and a different result can be achieved on the tennis court. We present these characteristics below. The next table is founded on the most difficult database that was put together in this research. There is very limited existing research in this area and we must rely on the expertise of the coaching staff to help define important relationships. The database for this level required a unique and timely effort to analyze and translate certain features of the team's behavior while framing those features in to defined concepts of literature. For instance, seeing a player perform a return of serve when his body is moving away from the ball instead of moving towards the ball, means that he failed to anticipate where the ball is oriented by his opponent. This is only one instance where anticipation can be identified. In order to figure out how to aggregate the relative weight, the SDI methodology was used.

Table 2.4 is one of the most fascinating findings from the SDI methodology. From the way that the coaching staff and the research knowledge interpret their value perception in a tennis player, we are obtaining aggregated statistical information of the team profile performance characteristics of behavior.

- The statistical analysis defines four main strategic values that characterize the necessary elements of behavior where the team needs to pay special attention, however two of them demonstrate higher effect. Anticipation is the ability to predict what is going to happen from the sensory input that we receive. For example, the ability to predict the opponent's movement direction, serve direction, next shot selection, etc. We can see that this element interacts with 83% of the second order characteristics. Therefore, it could cause a significant change in a player's performance capability. Alertness is the ability to detect the smallest changes in the environment. Players need to notice their environment (which includes changes in strategy, tactical and mental mode features of their opponent) in order to increase their performance level.
- The tactical analysis can characterize how a person should respond to a certain situation. It addresses the execution capabilities of the strategic decision. We can see that there is a significant difference between the shortage effect and the overage effect in most of the traits. Therefore, in order to improve the team's performance, the team needs to strengthen those values that possess a higher percentile effect when they are in shortage of use. Moreover, we can see that the effect of overage is pretty low by

Table 2.4: Third order relationships

Direct characteristic/trait	%	Cumulative error effect	
		High value/over use	Low value/under use
Strategy 47.5%			
Anticipation	14%	16%	84%
Alertness	16%	7%	93%
Cleverness	9%	49%	51%
Intuition	9%	52%	48%
Tactics 39.1%			
Adaptability	4%	16%	84%
Aggressiveness	2%	50%	50%
Determination	4%	14%	86%
Endurance	4%	18%	82%
Patience	4%	24%	76%
Composure	5%	0%	100%
Precision	4%	27%	73%
Assertiveness	5%	5%	95%
Agility	4%	16%	87%
Imagination	4%	9%	91%
Mental mode 13.4%			
Appreciation	1.1%	21%	79%
Honesty/integrity	1.2%	13%	87%
Valor/courage	0.9%	66%	34%
Principles guided	0.9%	63%	37%
Leadership	0.7%	49%	51%
Responsibility	1.3%	6%	94%
Enjoyment	1.2%	11%	89%
Motivation	1.2%	11%	89%
Reliability	1.2%	11%	89%
Self-discipline	1.0%	27%	73%
Compassion	1.0%	27%	73%
Professionalism	1.1%	16%	84%
Devotion	0.8%	40%	60%

comparison. This implies that relaxing these values would have little effect on the team's performance.

- The mental mode analysis identifies 13 items that characterize behavior. We can see that the dominant values are honesty, responsibility, enjoyment, motivation, reliability and professionalism. Improvement in each one of those traits would significantly increase the team's performance capabilities. Moreover, we can see that the overage of those traits (with the exception of valor, guiding principles and leadership) does not have a great impact on error creation because of their positive effect on the team's performance capabilities.

The SDI methodology addressed three-level orders that are connected through the classification of strategy, tactics and mental mode. The analysis provided a database for improvement that could be used to increase the team's performance. Implementing these recommendations in the player's physical

training program, game plan development education and in the tennis program structure will result in greater achievements.

2.6 Future research

In order to advance to the second stage of the SDI methodology which addresses cause and effect relationship with the addition of a time element and intensity scale, we will engage in computer simulation model development. The simulation model will allow the research team to explore the responsiveness of a player's current ability based on the time-based decisions (and level of intensity of those decisions) that are applied during game settings. The time scale would likely be different for each order level when considering the ability to create a performance change. For instance, creating a performance change based on first order characteristics would be relatively easy to implement but its ability to result in long-lasting change is less likely. In contrast, creating a performance change based on second order characteristics would be much harder (from the former example) to implement but its effect would likely last longer. In order to teach a child how to correct his spelling mistakes could be relatively easier when you correct his mistakes as he is speaking but that correction last only momentarily. However, if a spelling mistake is explained to the child, it will be harder and take more time, but he may never make the same mistake again. We will further explore the long-term benefits of addressing second- and third-order traits via the simulation modeling approach. We will also try to identify elements of human behavior that could create a trigger for performance improvement. Grunting, for example, is a physical element of performance when the player releases airflow while performing a certain shot, thus allowing his body to function without air congestion and to increase his motion. The improved motion could generate more power, faster reaction time and greater stability. Interestingly, the physical aspect of grunting may not even be the dominant cause for performance improvement. The mental aspect of grunting seems to be more beneficial to performance improvement as it triggers positive outcomes in attitude, character and confidence. The connections to higher order performance effects will be investigated further.

2.7 Discussion

When we consider performance improvements methods, we need a method that would adapt itself to. This research exposes the ability to define the KPIs, although for a tennis player KPIs are learned through many in the real time measurements of KPI. It is a closed loop concept that leads to continuous improvement

methods such as trial and error, video recordings of matches, books, papers and other sources. The SDI error listing, characteristics and traits can be unique for each player and using the player's feedback a continuous improvement approach can be achieved in the player's abilities. When considering the second and third-order characteristics, implementing this methodology may result not only in improvement in player's tennis game but also in the individual's daily life.

2.8 Conclusions

Quality development is one of the most desired features in industry today. It began its journey almost a century ago with simple process charts and reached multidisciplinary tools for process improvements. The SDI methodology was developed as a quality development tool for improved performance. In this research, an implementation of the SDI method revealed interesting findings on the tennis player performance characteristics. Those findings resulted in the creation of a team performance profile for the Clemson University tennis team. While the current possibilities for improved performance have been outlined, the next stage of this research is to create a dynamic system where the player interacts with another player and performance of each player is monitored and recorded. This can be accomplished through a mathematical tool such as computer simulation. Through the interaction between the players, the game features would be tested for their performance application. A statistical definition would be created to a certain strategy and the level of effectiveness could be measured. This is one of the fascinating research areas that take its first steps in the current field as it absorbs information and methodologies from the industrial engineering discipline and implements those techniques in professional sports.

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Chapter 3

Improving The Player's Recruitment Process Using Scenario-Based Decision Making Analysis

3.1 Abstract

High performance physical characteristics can be found today in most of the potential recruits for any athletic program and it has become increasingly difficult to select the right candidate based solely on these characteristics. As a result there is a growing need for a recruiter to evaluate the decision-making capability of a player in order to understand the mind of the player in addition to the player physical assessment. We employ scenario-based analysis to evaluate such decision-making capabilities while enabling any recruiting to customize the potential candidate evaluation, based on the specific program's needs. The proposed method provides a platform for decision making evaluation within a specific sport position through the use of game theory approach. In particular, we assess decisions that a player would make based on being given certain game scenarios, in an effort to identify the player's decision making type. The performance level of the athletic program depends heavily on its recruits, and scenario-based analysis can significantly enhance the capability to find the right recruit for the right position in the game and as a result, improve the athletic program management.

3.2 Introduction

Evaluating the decision-making capabilities of a potential candidate has not received the attention it deserves in the recruiting process, yet it can be one of the most critical performance determinants in game situations. Many professional recruiters tend to evaluate the physical capabilities of the player, some consider the raw talent of the player, and others still assess the player's social skills and work ethic. In the research by Dumond et al. (2008), it was demonstrated that Rivals.com, a player licensing and marketing company, utilizes various parameters and provides generic statistics of the player performance. Thus, an economic module has been conceptualized to assist in predicting player performance, but it does not indicate the player's decision-making capabilities that would enable the college recruiter to estimate performance relevant to their specific program. A multivariate model of a player's success, suggested by Spieler et al. (2008), used similar demographic characteristics. Although physical and environmental characteristics are significant factors in recruiting, Griffith et al. (1928) initiated an approach that demonstrated how there are key player characteristics, specifically psychological traits, which might prove to be more valuable. Furthering this line of research, Niednagel et al. (1992) created a classification system of sixteen groups that would define a player's brain type. Although significant steps were taken to advance the ability to recognize potential, the task of finding the suitable player for the right position in a specific program remains as the main challenge in the recruiting process. One of the reasons is that each program manager or head coach has his/her own unique game plan, which contains a combination of various strategies and tactics. As each game plan requires different characteristics of each player/team position in the game, the coach needs to change his players for efficient player-position fit. This is the essence of recruiting and could explain why a certain player can be a successful recruit for one team but an unsuccessful recruit for another. The study of Patil and Pasodi (2012) revealed the inherent difficulty of communicating with an athlete during the recruiting process and, thus, demonstrated that an interview analysis can help bridge the gap between the coach's expectation and the player's expectation for a certain position in the game. They have indicated that more research is required in order to examine the difference between successful and unsuccessful recruits. As such, the present research would complement this line of research by evaluating the player's cognitive capabilities. Many athletic programs structure their recruiting methods to rely solely on the player's physical capabilities, only to discover that their recruits fail to deliver the expected level of performance at game time. Linhares et al. (2012) presented the hierarchy of processing in the decision making phase as well as the capability difference between a skilled thinker and a novice one. Each decision level describes a type of thinking that aids the recruiter in classifying players based on their unique decision processing. Diverse patterns may

explain why successful doubles tennis players are not as successful in singles matches, or why a superb snooker player may not be as successful at pool. According to Ilundin-Agurruza (2015) and Park et al. (2015), brain EEG technology can demonstrate the difference between processing capabilities in high level players as apposed to amateurs. Each player in the game has a given decision space that determines his ability to maximize his potential. The player must be able to adapt by incorporating real-time information during the game to making his decisions accordingly.

Although these examples may have players with identical physical capabilities, the decision-making capabilities are completely different from one type of player to another. With more research and attention based on evaluating the cognitive aspects of players, progress can be made in understanding the future potential of a player. In the next section, we evaluate the recruitment process tools and their use across four different college sports. In sections 3 and 4 we introduce the player recruitment logic and framework. In section 5 we employ our suggested framework and evaluate several players from the Clemson club tennis team. We provide conclusions and recommendation for future work in section 6.

3.3 The Recruitment Process and its Tools

Player-position recruitment is a process containing a high level of uncertainty that athletic programs are trying to eliminate. From the introduction we can understand that there is great difficulty in assessing potential candidates. In order to overcome these difficulties, each sports program creates its own set of tools in order to improve recruitment success. For example, when evaluating a baseball pitcher, according to Dan et al. (2010), the Defensive Independent Pitching Statistic (DIPS) is used in order to evaluate the level of a pitcher. A pitcher's earned run average (ERA) is at least somewhat dependent on his defensive teammates that play behind him, and DIPS tries to evaluate the pitcher based solely on variables that he can control. Dan and Davis (2010) showed that the three most important variables that correlate strongly to positive performance for pitchers were (1) strikeout rates, (2) walk rates, and to a lesser degree, (3) home-run rates. The statistic is very helpful when evaluating past performance of pitchers, but is not as valuable when trying to gauge the potential of a pitcher, especially when the pitcher is moving from one level of competition to a higher level. A complementary approach to the statistical findings and analysis of player performance is the four A's methodology according to Scott et al. (1996). Since baseball is considered to have a unique rhythm, the team performance is heavily determined by the individual maturity of the players; thus, the recruitment process must account for more than statistical data. In assessing the academics, ability, attitude and adjustment capabilities of the recruitment candidate, the recruiter can receive an in-depth profile of the

player patterns of behavior. Although implementing the four A's might be an essential tool for any given athletic program, there is still a high level of uncertainty, as this method's main assumption is that past behavior patterns will continue in the future. Moreover, the transition from high school to college or from college to professional have a tremendous effect on a player performance.

A recruitment example from the sport of American Football. The cornerback position as described by former University of Toledo head coach Frank Lauterbur, must have great speed and quickness, must be a good-to-fair tackler, and must like to hit (Lauterbur 2000). He must be able to cover open receivers to prevent them from catching passes. Traditionally, cornerbacks have been smaller than receivers, primarily because smaller players generally had more speed and agility than taller players. According to Miller (2014), popular sports scouting and news site Bleacher Report states that an ideal corner's size is over 5'10" tall and weighs around 200 pounds. Shorter, lighter corners may have trouble keeping up with today's receivers that are often 6'4" or taller. In Miller's description of recruiting tools for such a position, recruiters measure the athlete's forty-yard dash time. This test not only evaluates the athlete's straight-line speed but also gives insight into the athlete's explosion and acceleration rate. Nelson (1994) describes that one of the main areas of the cornerback's body scouts observe is how well he can turn his hips. The quicker a cornerback can change his hips, the less ground he gives up to the receiver when covering the receiver's route. Moreover, a cornerback must have good technique in his backpedal as the transition to a full sprint should be abrupt, explosive, and in one movement. Recruiters will look for the way a cornerback breaks on the ball once it is thrown, whether he is still in his backpedal or already in stride with the receiver.

Besides the physical demands of the game, Scouts Inc. (2014) states that, aside from quarterbacks, cornerbacks require the most mental toughness of any player on the field. The mental part of the game is just as, if not more, important than the physical part of the game. Cornerbacks must have excellent anticipation because they have no idea where the wide receiver will make the cut in his route or exactly when the quarterback will throw the ball. They must also have great instincts in order to be in the right place at the right time. This is something scouts place great emphasis on when recruiting for the cornerback position. Corners need to have great awareness of the receiver, as he must be able to close the distance before the ball arrives.

Stepping away from the recruitment process in team sports, we now consider athlete recruitment within track and field - specifically the pole vaulter. Officially adopted at the first modern Olympic Games described in 1896, Jordan (2014), state that pole vaulting may present the highest level of requirements from its recruits. The sport began back in the days of the ancient Greeks, where poles were used as means of

avoiding obstacles and jumping over animals. Since those days, the sport has become highly versatile and incredibly challenging, according to McCormick (2010). A recruiter may consider a variety of details such as the athletes initial stance, how he or she grips the pole, the manner in which he or she sprints, the motions that take place during the planting of the pole, how the athlete manipulates his or her body during the swing up, how the athlete orients himself or herself when jumping over the bar, the athlete's speed, strength, explosiveness as well as mental characteristics such as body awareness, fearlessness, thought process, visual processing and many more factors. According to Risk (2000), vision plays a critical part in pole vaulting. The depth perception and visual tracking are important when making jump decisions. He concludes that he requires his athletes to take an 11-part test when not only recruiting but also for the development of the athletes. This allowed him to further train the team on certain vision techniques. As the National Pole Vault Chair for Canada during the 2000 Sydney Olympics, he often assessed the sprints, long jump, and hurdle events for future pole vaulting recruits due to requirements of speed and agility. He also emphasized the importance of the recruitment candidate's academic performance, because it often facilitates efficient learning and training of techniques. Lastly, he wrote that he had to make sure that this potential team member gels with the current team, in order to avoid any future conflicts. According to Nyberg (2014) there is a great difference between the physical characteristics and the mental characteristics that are expected from a pole vaulter. He discusses the complementary ability to use cognitive skills and perform an intended motor skill, such as reading music while playing the piano, and the ability to use motor skills to perform cognitive skills such as using a calculator to solve a math problem. Because this sport is very complex, the mental characteristics play a critical role for evaluating potential recruits. Thus, a tool that would help create a pole vaulter profile may reduce the level of uncertainty in the recruitment process.

While pole vaulting athletes are faced with a static challenge (a bar), tennis players are presented with a challenge in a dynamic setting (an opponent), with feedback from a certain course of action chosen by the player. According to Shvorin and Taaffe (2014), there are many performance characteristics that could be evaluated during the recruiting process. Each performance characteristic may have a direct or indirect effect on the player decision-making process that translates into a defined level of performance. Upon creating a profile for the player decision making capability, the improvement potential may be evaluated in greater depth as decision making patterns have a direct impact in real time performance in the game. In the next section we will provide inferences about the recruitment process and its tools, and provide reasoning for creating a generic tool with customizing application for each athletic discipline. Such a tool is expected to improve the recruitment process and the athletic program as a whole.

The review of the four position recruitment characteristics indicates the growing need for a systematic method to evaluate the decision-making capabilities of the athlete as the human physical capabilities have reached a certain plateau. It is becoming increasingly difficult to achieve an advantage in performance based solely on physical features when most of the elite athletes have similar characteristics. Thus, identification of the player's thinking patterns undoubtedly will better inform the level of expected performance. Although there are different performance requirements in each athletic program, we can see that there is common ground where decision making capabilities can be tested. Moreover, while game scenarios can be customized to each sport and its demand characteristics, the ability to make decisions rests with the player's predominant patterns of thinking, individual interpretation, analytic analysis, comprehension, and execution abilities. In the next two sections we will focus on the methodology development and provide the basic structure for evaluating a player's decision making capabilities, using a game theoretic approach.

3.4 Player Recruitment using Game Theory

Recruiting a potential candidate requires great effort on behalf of the athletic management team. Each scout or coach is trying to predict performance potential when integrating subjective experience and expertise. The difficulty that the management team is faced with is identifying a candidate who, after receiving team training and coaching, will be able to make smart decisions in actual game situations. Making the right (or smart) decision requires knowing the decision that will produce the highest gain or payoff for the team in that specific scenario. Game theory is often employed to calculate mathematically what the best response would be (Tadelis, 2013). Such an approach could also be used to test recruitment candidates by scripting various game-time scenarios and measuring their performance using a scenario-based approach. After a brief introduction to game theory in this section, we explore the model development process and employ that framework in a case study with current college tennis players.

3.4.1 Game theory approach description

The setting of the game is one of the most important aspects as it determines certain values in the model and the decision-making alternatives that are being addressed. The most basic game theoretic model, including both uncertainty and time elements, can be found in the calculation of expected value from a decision-making tree (Tadelis, 2013). In order to establish a meaningful decision-making process, the player must be able to compare uncertain consequences when he makes a certain decision. We introduce a

simple lottery model in this section to describe the decision-making process. Consider a decision situation where x_i denotes the i^{th} outcome ($i = 1, \dots, n$), thus by definition, a simple lottery over outcomes $X = (x_1, x_2, x_3, \dots, x_n)$ is defined as a probability distribution $P = (p(x_1), p(x_2), p(x_3), \dots, p(x_n))$ where $p(x) \geq 0$ is the probability that x_i occurs and $\sum p(x_i) = 1$. The next example can explain the simple model structure.

Consider a simple lottery model where player has a 70% chance to receive \$10 if he chooses lottery A and 80% chance to receive \$8 if he chooses lottery B. In order to evaluate a certain decision in an uncertain condition we will use the expected payoff calculation. By definition, if $u(x)$ is the payoff function (utility) of the player over outcomes of $X = (x_1, x_2, x_3, \dots, x_n)$ such that $p(x)$ is a lottery over X , and $p(x_i) = P_r(x = x_i)$, then we define the expected payoff from lottery $p(x)$ as:

$$E[u(x)|p(x)] = \sum_{i=1}^n p(x_i) \cdot u(x_i) = p(x_1) \cdot u(x_1) + p(x_2) \cdot u(x_2) + p(x_3) \cdot u(x_3) + \dots + p(x_n) \cdot u(x_n) \quad (3.1)$$

In order to evaluate the simple lottery, lottery A returns a \$7 expected payoff and lottery B returns a \$6.40 expected payoff. Therefore, a rational player who would like to maximize his profit should choose to play lottery A, despite the higher probability of success associated with lottery B. In order to utilize this simple model in the recruiting process we need to define certain basic characteristics in the decision making space. Similar to the lottery example, a sport recruit will need to decide between a number of alternative in order to identify the best decision in a specific scenario settings. From the simple lottery model we can understand that there are a few guidelines that need to be defined in order to create a decision-making evaluation for a potential recruit.

3.5 The Recruitment Framework

In this section, we present the recruitment model that evaluates a player's approach to decision making in game scenarios. To make use of our approach, we assume that the coaching staff has a need at a particular player position. Each sport has its own set of unique player positions, and each position requires unique player characteristics. Moreover, desirable player characteristics could vary among teams, due to the abilities of existing players on the team and the strategic plan of the coaching staff. For example, in Basketball, a point guard who is highly skilled in maneuvering the ball would be a key player to recruit in a team that already has skills in shooting guards, power forwards and centers. However, a team that is disadvantaged in these positions may require a point guard who is a skilled shooting guard as well, in

order for him to have the desired impact or significance. This is just one aspect of player characteristics that should be addressed in the recruiting process and, thus, it is extremely important to determine exactly what the goals are for the recruiter. In preparing the player recruitment analysis, the following steps in a player recruitment model are proposed.

1. Describe the specific game scenario
2. Map the player's decision alternatives
3. Identify performance characteristics critical in decision making
4. Create a performance scale and evaluate a player's relative advantage
5. Perform cost and benefit analysis for the possible decision alternatives
6. Quantify execution capabilities and decision making
7. Guidelines for a decision making question

3.5.1 Describe the specific game scenario

We must first describe a specific scenario in the game that challenges a player's decision-making. Each coach has his/her own unique set of strategies and tactics he uses to govern the players in the game. There are many situations in the game that can demonstrate the decisions of the players; thus, if the decision follows the guidelines of the coach, the player would meet the coach's expectations. However, if the decision of the player is different from the coach's expectation, it creates difficulty for the coach to establish tactical plays in the game. A player's decision-making process should be evaluated in the recruitment stage rather than during real-time performance. By evaluating the thinking preferences of the player early in the recruiting process, the recruiter would quickly recognize player compatibility with the coach's approach to the game. This compatibility would prove to be most valuable in real-time under pressure where the cognitive capability and the motor skill of the player are put to the test.

3.5.2 Map the player's decision alternatives

There are many levels of decision-making in the game and many different player positions. A player could be a part of a team and have a determined decision-making space (e.g. basketball players positions) or he could be an independent individual responsible for a wider space of decision making in the game

(e.g. tennis, ping-pong, snooker). The space of the player decision-making can be very large or very small; however, the importance of the decision is independent of the size of the decision-making space.

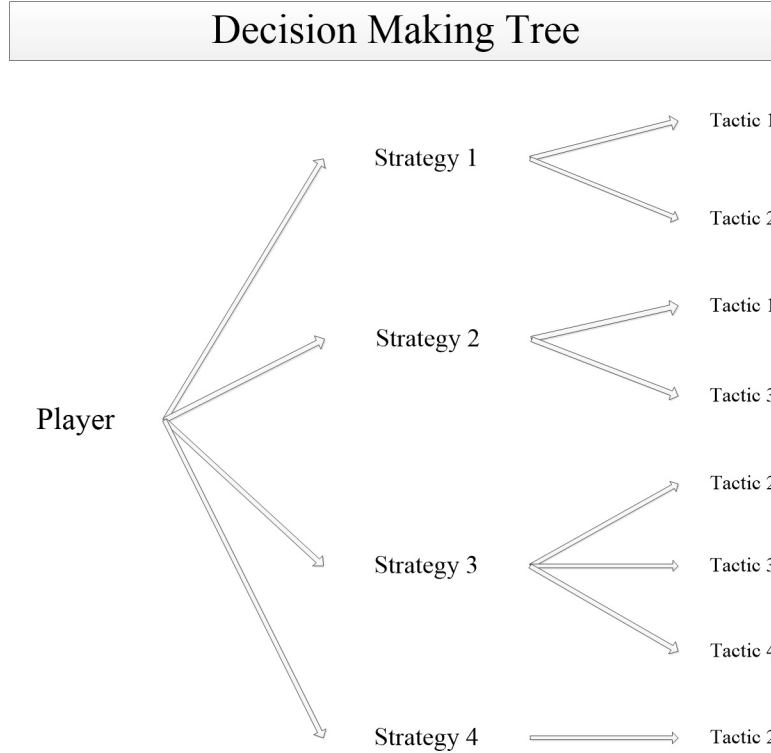
Each position may require up to two levels of decision-making: a strategic decision and a tactical decision. In some disciplines there is much confusion among professionals regarding the definition of the two concepts, however, this research aims to create a common language. A strategy is the overarching objective that aims to take advantage of the gap between the cumulative strengths and cumulative weaknesses. We suggest identifying a strategy by answering the following question: *What do I need to do in order to win the game?* Examples could be to play at a fast pace, play with power or be aggressive, play with patience, play to the weaker side of the opponent, play with high consistency, play under pressure and play to create the element of surprise. A tactic, on the other hand, is a short-term alternative that helps attain the overall strategy as well as aims to take advantage of the gap between strengths and weaknesses in an isolated situation. We suggest identifying a tactic by answering the following question: *How should I achieve my selected strategy?* A few examples here would create the set of alternatives for the chosen strategy. If we assume that our strategy is to play at a fast pace, tactical alternatives could be to physically perform activities faster, eliminate any disturbances, breaks or delays during the game to increase game flow, execute operations sooner so that the opponent would have less time to prepare, etc.

Consider the following scenario. A quarterback leads his team by selecting a certain play to run that will give the team the highest payoff in his objective of yards gained towards a touchdown. In selecting a strategy, he asks himself what he should do in order to have the highest probability of scoring a touchdown or advancing in the field. Our quarterback identified that the rival team has weaker defensive capabilities on the left side based on prior experience. Thus, his strategy is to play to the weaker left side of the rival team. In selecting a tactic, he needs to decide which play to run. Thus, a tactic would be to select one among alternatives, such as a long pass, a short pass, an inside run, etc. Evaluating the position decision-making choices would lead to a creation of a decision making tree that articulates the possible strategies and tactics from which to choose.

A decision tree can demonstrate the decision process according to the selected scenario. Figure 3.1 demonstrates how to map out the decision-making process for a given scenario in the game. The player can choose between four different strategies in the given scenario. Each strategy presents different tactic alternatives and, in some cases, the same tactic alternatives (tactic 2 can be selected for strategies 1, 3, 4). The key outcome is the establishment of a game plan. A game plan, by definition in this research, is the set of decisions selected for execution by the player. Let S and T denote the sets of strategies and tactics

available at this player position. Consider a strategy $s \in S$ and a tactic $t \in T$. This $\{s, t\}$ combination represents one decision making possibility from the set of game plans G , where $\{s, t\} \in G$. When taking under consideration the alternatives in Figure 3.1, we can see that the player has eight different decisions from which to choose in a certain scenario.

Figure 3.1: Mapping possible strategies and tactics



3.5.3 Identify decision making performance characteristics

Performance characteristics are features of physical, mental and emotional capability that affect the quality of any activity that is executed in the game. These features are inputs into our decision-making process and are the key ingredients for creating a winning game plan. Unlike the lottery model where we deduce our ability to win by calculating a static probability, identifying a game plan that presents the highest probability to win requires a synthesis of human performance characteristics and their impact on the decision-making alternatives. Physical performance characteristics are more concrete and, as such, easier to identify, whereas mental and emotional performance characteristics are more challenging to identify.

In each game scenario, some performance characteristics are more salient than others in the player decision-making process, and it is up to the player to take them into consideration. For example, a boxer

starting his first round recognizes that his opponent has very quick jabs and moves quickly. The boxer also notices his advantage in delivering more powerful punches. In this scenario, the performance characteristics that play a critical role are the boxer's agility, endurance and power. Assuming that our boxer is starting the fifth round, he notices that his fast and agile opponent begins to anticipate his slow but powerful punches. Moreover, his opponent is demonstrating a behavior of superiority and ego, while our boxer demonstrates a calm and collected behavior. In this example, the performance characteristics that play a critical role in the decision-making process are the ones that reflect the relative advantage between the two boxers such as anticipation, awareness, focus and arrogance. In order to devise a winning game plan for both boxers, we need to consider the physical, mental and emotional performance characteristics of each one.

When considering these performance characteristics, one game plan for our boxer could be to conserve effort, move the opponent around so he will get tired, present a high variety of punches and go for the knockout punch. On the other hand, his opponent's game plan could be to circle around while studying moves, demonstrating irritating behavior in order to create distractions, and deliver as many punches to establish a high scoring margin. Selecting the performance characteristics and identifying an appropriate performance scale for representation is explained in the following section.

3.5.4 Evaluate players relative advantage

It is very difficult to quantify the level of a certain performance characteristic in a player; however, it is more attainable to define performance characteristics relative to other players or teams. Each player needs to be able to assess himself as well as his opponent in order to determine what are his strengths and weaknesses. This scaling process is used in quality engineering as it helps reduce uncertainty and create a quantified method for continuous improvement. In Montgomery (2013) and Foster (2013) as well as many more quality engineering educational text books, many tools require scaling. For example, quality function deployment (QFD), failure mode and effects analysis (FMEA), servqual, prioritization grids, matrix diagrams and six sigma (DMAIC), have a way to determine relativity between factors of influence. In our case, human performance characteristics needs to be scaled in order to identify relative advantage. For example, height is a basic parameter that contains inherent scaling in inches or centimeters. This characteristic can pose a major element for a point guard when he is considering a two-point shot or a three-point shot. The same reasoning can be inferred from other performance characteristics such as anticipation, adaptability, endurance, patience, agility as they are all participating in our decision making process.

This is the basic stage for evaluating a certain decision in the game, as each decision can be compiled

from different performance characteristics. Consider a group of individual players whose performance will be measured. A performance characteristic can be defined as any characteristic of type pc_i where $i = 1, 2, 3 \dots n$. The level of a performance characteristic i for player 1 can be denoted as $l_i(1)$. The relative advantage emerges from the difference between the levels of each player's performance characteristic. In order to explain this method consider the following example:

In this example, we focus on comparing the abilities of two players. A strength s_i of player 1 can be denoted if $[l_i(1) - l_i(2) > 0]$ and a weakness w_i of player 1 can be denoted if $[l_i(1) - l_i(2) < 0]$. The advantage scale will always be presented as $|l_i(1) - l_i(2)|$. From Table 3.1, we can see which performance characteristics play a critical role in the decision-making process of player 1 in a certain scenario.

Table 3.1: Performance characteristics assessment

(i)	Performance Characteristics (pc_i)	$l_i(1)$	$l_i(2)$
1	Anticipation	5	8
2	Adaptability	5	9
3	Endurance	7	5
4	Patience	9	4

From this analysis we can see that player (1) has a relative advantage in his endurance capability and in his patience, thus $s_{(1)} = \{endurance, patience\}$. Player 2 has a relative advantage in anticipation and adaptability, therefore $s_{(2)} = \{anticipation, adaptability\}$. If we can look at this analysis from a general point of view, some strategies and tactics should come to mind in order to maximize the performance of player 1 or 2 in the game. In the next section, we will construct a cost and benefit analysis when considering certain decisions in the game.

3.5.5 Perform cost and benefit analysis for the possible decision alternatives

From Section 3.1 (lottery model) we saw that the model presented a prize and a risk (winning probability) associated with each possibility. Different from the lottery model, prizes and risks in this research methodology are not given but rather created, based on the analysis of the player's performance characteristics, game plan selection and execution capabilities.

In order to create a game plan the player must select a strategy and a tactic. Each strategy and tactic combination has certain performance characteristics mentioned in the prior section. In order to determine the benefit or cost resulting from a certain decision in the game, the advantage scale is utilized. The player benefits and costs are denoted as the average relative advantage, or disadvantage, from a certain strategical and tactical decisions. The average benefit of Tactic i for player 1 can be denoted as:

$$tb_i(1) = \frac{\sum_{j: l_{j(1)} \geq l_{j(2)}; j \in T_i^{PC}} [l_j(1) - l_j(2)]}{|T_i^{PC}|} \quad (3.2)$$

The average cost of Tactic i for player 1 can be denoted as:

$$tc_i(1) = \frac{\sum_{j: l_{j(1)} \leq l_{j(2)}; j \in T_i^{PC}} [l_j(1) - l_j(2)]}{|T_i^{PC}|} \quad (3.3)$$

When looking at the example from Table 3.1 and the decision making mapping from Figure 3.1 we can see that there are four available tactics to select from. Each tactic presents different characteristics that are critical to the player performance. In Table 3.2 we assign the performance characteristics that are involved in each tactic and in Table 3.3 calculate the benefit and cost using equations (2) and (3).

Table 3.2: Performance characteristics assignment

(i)	Performance Characteristics (pc_i)	$l_i(1)$	$l_i(2)$	Tactic 1	Tactic 2	Tactic 3	Tactic 4
1	Anticipation	5	8	v		v	
2	Adaptability	5	9		v	v	v
3	Endurance	7	5	v	v	v	
4	Patience	9	4	v			v

Table 3.2 shows that tactic 1 has three performance characteristics that play a critical role in the player performance. Endurance means that this tactic includes intensive physical effort. Anticipation presents the capability to surprise the opponent and patience reflects the consideration of time. In tennis for example, playing long rallies while trying to wrong foot the opponent can explain what tactic 1 might look like in the game.

Table 3.3: Tactic benefits and costs for player 1

(i)	Tactic 1		Tactic 2		Tactic 3		Tactic 4	
	Benefit	Cost	Benefit	Cost	Benefit	Cost	Benefit	Cost
1	-	3			-	3		
2			-	4	-	4	-	4
3	2	-	2	-	2	-		
4	5	-					5	-
$tb_{i(1)}$ and $tc_{i(1)}$	2.33	1	1	2	0.67	2.33	2.5	2

Table 3.3 demonstrates how to calculate the average benefit and cost for a certain tactic based on which PC's are critical for the tactic performance. The number of PC's involved changes from one tactic

to another, thus an average can maintain relativity among tactics. In addition, each tactic has a certain probability of success when the player is executing it such that if the player successfully execute his tactic then he is rewarded by the tactic benefit, but if he fails to execute his tactic, he accepts the value of his loss. In the next section we will continue this discussion in more detail.

3.5.6 Quantify execution quality

Establishing a clear connection between the plan type and the likelihood for execution success is critical. We ensure reliability in the decision making evaluation by incorporating execution quality into the measurement. The value of execution quality represents the ability to deliver a consistent level of performance, regardless of the conditions or environment. Identifying and measuring a player's execution quality in this context requires the expertise of the coach in order to evaluate the long run probability of success for each tactic in a certain scenario. Since it is very difficult to provide a single value to represent this qualitative measurement, we propose a tolerance for execution capability.

Table 3.4: Execution capability scale

Execution Capabilities Scale	Probability of Success	
	Lower bound	Upper bound
Low	20%	40%
Average	50%	70%
High	80%	95%

In Table 3.4 we see three levels (and ranges) of execution capability and the probability of success that is associated with each level. This table will help us evaluate the best decision for a certain scenario in the game as it represents the variability for ranges of performance. This range allows the coach to assign the long run probabilities for the tactic success when considering the player execution capabilities. Low level means that the player is having difficulty in executing a certain type of tactic. Average level means that the execution capability of the player is partly successful. High level means that the player execution is really good and can perform a certain tactic with ease. Each tactic may present a certain reward if is successfully executed however the level of risk involve is express through the player probability of success, thus the couch needs to find the right mix between a certain tactic selection and its execution capability. In the next section we demonstrate the utilization of the execution quality scale.

3.5.7 Quantify strategies and tactics

In Figure 3.2 we present the decision tree structure when uploading the information from Table 3.3 and assigning the execution quality to each tactical decision as articulated in Table 3.4. We can see that Tactic 1 and Tactic 3 have a high level of execution quality while Tactic 2 and Tactic 4 have average and low execution quality respectively. With this scheme we utilize formula 1 to calculate the expected payoff for Tactics 1 thought 4. For example, Tactic 1 expected payoff can be denoted as: $E[t_1(value)|p(quality)] = p_1(success) \cdot tb_1(benefit) - p_1(failure) \cdot tc_1(cost) = 0.9 \cdot 1 - 0.1 \cdot 2.33 = 0.667$ The next table present the Tactics expected payoff summary for scenario (X).

Figure 3.2: Structuring benefit, cost and execution quality to the decision making tree

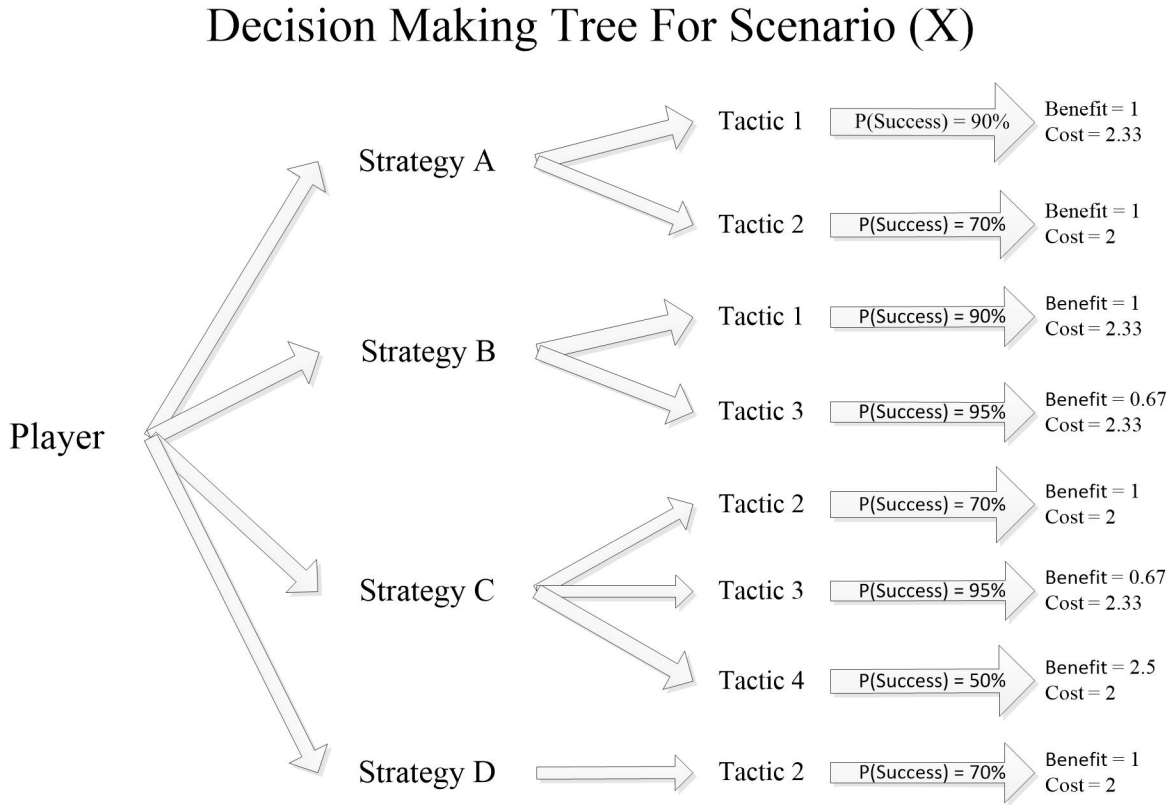


Table 3.5: Scenario (x) tactics expected payoff summary

Tactic	Tactic Expected Payoff
Tactic 1	0.6
Tactic 2	0.1
Tactic 3	0.5
Tactic 4	0.2

The expected payoff from selecting a certain tactic will involve the benefit and cost analysis while considering the execution quality associated with it. Utilizing formula 1 we denote the tactic expected payoff as:

$$E[t_i(value)|p(quality)] = p_i(success) \cdot tb_i(benefit) - p_i(failure) \cdot tc_i(cost) \quad (3.4)$$

3.5.8 Quantify the game structure

In order to create a plan for the game at any level the opponent capabilities and decision making needs to be evaluated. Moreover, a prediction of response should be assign to each situation in order to create the best game plan. According to our framework the basic relative advantage analysis from Table 3.2 and Table 3.3 may give us the basic intuition. The next model can articulate the basic structure for evaluating a game plan (See appendix Table 3.10 & 3.11).

1. Players: N=1,2

2. Strategy Sets:

S1 = Strategy A, Strategy B, Strategy C for player 1 ∈ scenario (X)

S2=Strategy F, Strategy G for player 2 ∈ scenario (X)

3. Tactic Sets:

t1 = Tactic 1, Tactic 2, Tactic 3, Tactic 4 for player 1 ∈ scenario (X)

t2=Tactic 5, Tactic 6, Tactic 7, Tactic 8 for player 2 ∈ scenario (X)

Assuming we have created the same framework for player 2 and quantify the tactics (5,6) and strategies (F,G) values. The next table demonstrate the articulated payoff when considering the decisions of player 1 and player 2.

Table 3.6: Scenario (y) summary 1

%				P_A		P_B		P_C		
				Strategy A		Strategy B		Strategy C		
		%		$PA_{(T_1)}$	$PA_{(T_2)}$	$PB_{(T_1)}$	$PB_{(T_3)}$	$PC_{(T_2)}$	$PC_{(T_3)}$	$PC_{(T_4)}$
				Tactic 1	Tactic 2	Tactic 1	Tactic 3	Tactic 2	Tactic 3	Tactic 4
P_F	Strategy F	$PF_{(T_5)}$	Tactic 5	2.4 , 1.6	2.2 , -0.1	2.4 , 1.6	2.5 , 1.3	2.2 , -0.1	2.5 , 1.3	1.6 , -0.7
		$PF_{(T_6)}$	Tactic 6	3.3 , 4.5	3 , 2	3.3 , 4.5	3.3 , 4.1	3 , 2	3.3 , 4.1	2.7 , 0.7
P_G	Strategy G	$PG_{(T_7)}$	Tactic 7	2.9 , 2.6	2.6 , 0.9	2.9 , 2.6	2.9 , 2.3	2.6 , 0.9	2.9 , 2.3	2.3 , 0.2
		$PG_{(T_8)}$	Tactic 8	0.1 , 1.5	0 , -1	0.1 , 1.5	0.3 , 1.1	0 , -1	0.3 , 1.1	-1.2 , -2.2

When two tactics collide a new benefit and cost assessment will be made for each player as they may address difference performance characteristics. From this point, equation 4 will be apply to quantify

the expected payoff when considering the players execution capabilities. For example, when player 1 plays Tactic 1 from Strategy A and player 2 plays Tactic 5 from Strategy F, player 1 benefit and cost assessment can be articulated as such:

$$tb1_{new} = tb1 + tc2 \quad (3.5)$$

$$tc1_{new} = tc1 + tb2 \quad (3.6)$$

For example, if Tactic 5 benefit is 3 and cost is 1 with 60 % of success rate and Tactic 1 benefit is 1 and cost is 2.33 with 95 % of success rate then the new benefit and cost for tactic 1 and tactic 5 will be: $tb1 = 1 + 1 = 2$, $tc1 = 2.33 + 3 = 5.33$ and $tb5 = 3 + 2.33 = 5.33$, $tc5 = 1 + 1 = 2$, therefor $E[T1|T5] = 0.95 \cdot 2 - 0.05 \cdot 5.33 = \mathbf{1.6}$ and $E[T5|T1] = 0.6 \cdot 5.33 - 0.4 \cdot 2 = \mathbf{2.4}$. Using the same logic, Table 3.6 values where calculated.

Assessing Table 3.6 we can find that for each player there is a dominant Tactic. For player 1, playing Tactic 1 will always produce the highest payoff (looking at the right columns across the table). For player 2, Tactic 6 will always produce the biggest reward (looking at the rows when considering the left column). It is also against the interest of player 2 if the players decide to play both tactics with the highest payoff because ultimately player 2 will earn less points then player 1. If one of the players could have known what the other player is going to do (i.e which tactic he is going to execute) then that player can always select his best response and eventually will be favor to win the game. In real life there is much uncertainty thus our model mitigate this by enabling the players to assign probabilities when trying to predict what strategy P_i the other player will use over time as well as how would he mix his tactics $P_{i(Tj)}$.

3.5.9 Quantify and evaluate a game plan

There are various levels of decision making and each level can reveals certain capability. Different capabilities for decision making is associated with different player positions in the game. In the next sections we will address each level and demonstrate how this framework can impact recruiting assessments.

3.5.9.1 Localized Decision Making Capability

The setting for localized view include the players performance characteristics relative advantage knowledge, execution capability and tactical selection. The application for this decision can be articulated in the next question setup when addressing Table 3.6:

1. If player 1 knows that player 2 is going to play tactic 5 as well as his execution capability, what tactic should he select to play given his knowledge of the performance characteristics relative advantage and his execution capability when looking at his tactical selection in response

Isolating the localized decision making for player one regarding players two selection of playing tactic 5 would look like:

Table 3.7: Localized decision making cut off for tactic 5

	Tactic 1	Tactic 2	Tactic 1	Tactic 3	Tactic 2	Tactic 3	Tactic 4
Tactic 5	2.4 , 1.6	2.2 , -0.1	2.4 , 1.6	2.5 , 1.3	2.2 , -0.1	2.5 , 1.3	1.6 , -0.7

In this situation player 1 should select to play tactic 1, among the 4 tactics, as it provide the best response which provide the highest payoff. The quantification of this values is done according to the former section utilizing equation 4,5 and 6.

3.5.9.2 Short Term Decision Making Capability

The settings for short term decision making builds on the settings for localized decision making only includes a higher level of complexity. The question associated with this level is formulated in the next manner:

1. What tactic would player 1 should select when considering all tactical possibilities of player 2, given a prediction that quantify how player two will mix between tactics (play different tactics) over time?

Isolating the short term decision making for player one regarding players two selection of tactics would look like:

Table 3.8: Scenario (y) summary 2

%		$PA_{(T_1)}$	$PA_{(T_2)}$	$PB_{(T_1)}$	$PB_{(T_3)}$	$PC_{(T_2)}$	$PC_{(T_3)}$	$PC_{(T_4)}$
		Tactic 1	Tactic 2	Tactic 1	Tactic 3	Tactic 2	Tactic 3	Tactic 4
$PF_{(T_5)}$	Tactic 5	2.4 , 1.6	2.2 , -0.1	2.4 , 1.6	2.5 , 1.3	2.2 , -0.1	2.5 , 1.3	1.6 , -0.7
$PF_{(T_6)}$	Tactic 6	3.3 , 4.5	3 , 2	3.3 , 4.5	3.3 , 4.1	3 , 2	3.3 , 4.1	2.7 , 0.7
$PG_{(T_7)}$	Tactic 7	2.9 , 2.6	2.6 , 0.9	2.9 , 2.6	2.9 , 2.3	2.6 , 0.9	2.9 , 2.3	2.3 , 0.2
$PG_{(T_8)}$	Tactic 8	0.1 , 1.5	0 , -1	0.1 , 1.5	0.3 , 1.1	0 , -1	0.3 , 1.1	-1.2 , -2.2

The answer should be quantify as the expected value of a tactic when considering all possible tactics of player two while including the prediction of mixing between them over time. This answer can be denoted as:

$$E[T_p] = \sum_{(j=1 \dots m)} \frac{PS_{T_j}}{\sum PS_{(T_j(j=1 \dots m))}} \cdot E[T_i|T_j] \quad (3.7)$$

For example, if player 1 estimate that player 2 will mix between his tactics over time in this manner: $PF_{T_5} = 40\%$, $PF_{T_6} = 60\%$, $PG_{T_7} = 80\%$, $PG_{T_8} = 20\%$, then the expected payoff from playing his tactics will be:

$$E[T_1] = \frac{0.4}{2} \cdot 1.6 + \frac{0.6}{2} \cdot 4.5 + \frac{0.8}{2} \cdot 2.6 + \frac{0.2}{2} \cdot 1.5 = 2.86$$

$$E[T_2] = \frac{0.4}{2} \cdot (-0.1) + \frac{0.6}{2} \cdot 2 + \frac{0.8}{2} \cdot 0.9 + \frac{0.2}{2} \cdot (-1) = 0.84$$

$$E[T_3] = \frac{0.4}{2} \cdot 1.3 + \frac{0.6}{2} \cdot 4.1 + \frac{0.8}{2} \cdot 2.3 + \frac{0.2}{2} \cdot 1.1 = 2.52$$

$$E[T_4] = \frac{0.4}{2} \cdot (-0.7) + \frac{0.6}{2} \cdot 0.7 + \frac{0.8}{2} \cdot 0.2 + \frac{0.2}{2} \cdot (-2.2) = -0.07$$

In this setting, player 1 best response selection will be to play tactic 1 as it demonstrates the highest payoff. We can also see that there is a minor difference between tactic 1 and tactic 3 but a large difference between tactics 1 and 3 to tactics 2 and 4. When producing this type of question to a player that we intend to recruit it is logical that some flexibility can be given if the player select answers that contain tactic 1 and tactic 3, however if he selects answers containing tactics 2 and 4 we know that the player did not demonstrate a good capability in this question, thus his short term decision making score will be demonstrated in the evaluation report.

3.5.9.3 Long Term Decision Making Capability

The settings for long term decision making builds on the settings for short decision making only includes a higher level of complexity. The question associated with this level is formulated in the next manner:

1. What game plan should player 1 select given player 2 game plan?

This question address Table 3.6 in its completion. The answer to this question should be quantify as such:

$$E[GP] = \sum_{d=1 \dots m} PS_d \cdot \sum_{i=1 \dots n} PS_{T_i} \cdot \left\{ \sum_{k=1 \dots l} PS_k \cdot \sum_{J=1 \dots b} PS_{T_J} \cdot E[T_i|T_J] \right\} \quad (3.8)$$

For example, if player 2 will have this following game plan: $PF_{T_5} = 20\%$, $PF_{T_6} = 80\%$, $PG_{T_7} = 80\%$, $PG_{T_8} = 20\%$ as well as mix between his strategies in this way: $PF = 80\%$, $PG = 20\%$, then we can

evaluate player 1 payoff when compared to player 2. In this case we are providing 4 options to select from in this manner:

1. $PA = 10\%\{PA_{T_1} = 80\%, PA_{T_2} = 20\%\}, PB = 80\%\{PB_{T_1} = 80\%, PB_{T_3} = 20\%\}, PC = 10\%, \{PC_{T_2} = 10\%, PC_{T_3} = 80\%, PC_{T_4} = 10\%\}$
2. $PA = 20\%\{PA_{T_1} = 10\%, PA_{T_2} = 90\%\}, PB = 20\%\{PB_{T_1} = 10\%, PB_{T_3} = 90\%\}, PC = 60\%, \{PC_{T_2} = 10\%, PC_{T_3} = 10\%, PC_{T_4} = 80\%\}$
3. $PA = 30\%\{PA_{T_1} = 80\%, PA_{T_2} = 20\%\}, PB = 30\%\{PB_{T_1} = 80\%, PB_{T_3} = 20\%\}, PC = 40\%, \{PC_{T_2} = 10\%, PC_{T_3} = 60\%, PC_{T_4} = 30\%\}$
4. $PA = 20\%\{PA_{T_1} = 20\%, PA_{T_2} = 80\%\}, PB = 60\%\{PB_{T_1} = 20\%, PB_{T_3} = 80\%\}, PC = 20\%, \{PC_{T_2} = 10\%, PC_{T_3} = 10\%, PC_{T_4} = 80\%\}$

The following figure will demonstrate each game plan expected value among the 4 possibilities that the recruit will have to select from given his opponent game plan.

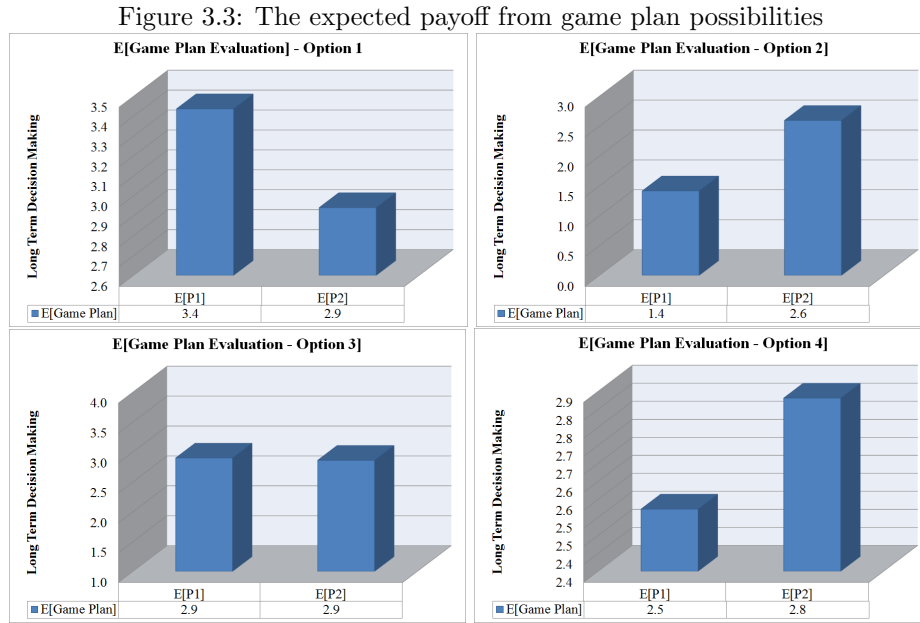


Figure 3.3 demonstrate that option 1 is the best game plan setup for player 1(The computation is addressed in the appendix). This decision is the most difficult to make as the recruit need to understand how performance characteristics establishes tactical benefits and costs which determine critical features when playing a certain strategy.

3.5.10 Guidelines for a decision making question

Assessing a player's decision making capability is a challenging, yet essential, task in evaluating the fit of the recruit for the particular program. In that process, the recruiter needs to validate that the recruit understand the questions and scenarios for which he is being evaluated. In order to reliably achieve such a task we offer a model that is adopted in the health care industry, Scholl et al. (2011). The goal of this model is to test the physician patient interaction when a course of treatment must be selected.

Similar to our approach, the physician needs to explain the scenario to the patient, explain the options of treatments available, and explain the benefits and costs associated with each alternative for the short term and the long term. In order to change these settings and test the decision making capability in the context of a tennis player, the consequences of the decision making alternatives are not discussed, therefore allowing the player to determine this on his own. If a player's decision matches or suits a the coach's approach then we have identified a fit.

The shared decision making model provide insights into the decision making process which we will conceptualize to achieve our evaluation objectives. Scholl et al. (2011) provided a review of this model in 2011, and Scholl et al. (2012) tested the model a year later with funding from the Germany Ministry of Health. They have concluded that the assessment tool is statistically valid and reliable. The model presents nine statements and an associated scale for each response. The statements are:

1. I made clear to my patient that a decision needs to be made
2. I wanted to know exactly from my patient how he/she wants to be involved in making the decision
3. I told my patient that there are different options for treating his/her medical condition
4. I precisely explained the advantages and disadvantages of the treatment options to my patient
5. I helped my patient understand all the information
6. I asked my patient which treatment option he/she prefers
7. My patient and I thoroughly weighed the different treatment options
8. My patient and I selected a treatment option together
9. My patient and I reached an agreement on how to proceed

In order to use this structure in the survey we offer in Section 3.6, several aspects of the above statements are incorporated into the questions and scenarios. Here are examples of how that is accomplished.

- Question introduction: A decision needs to be made in the following scenario and you will represent player A's best interests. You need to select one alternative that, in your opinion, will have the best consequence (addressing statement 1-3).
- Question body: In the following scenario, player A' has the advantage over his opponent in certain performance characteristics while his opponent has the advantage in other performance characteristics (addresses part 5 of the statement for the shared decision making model).
- Determine the type of decision making question you would like to address and provide the scenario details. For example, in localized decision making the scenario will be describe as such: Player A's opponent is playing Tactic 5 and have certain probability for implementing it in the game. Player A can select to implement Tactic 1, Tactic 2, Tactic 3 or Tactic 4 and his implementation success is a certain percent for Tactic 1, a certain percent for Tactic 2, a certain percent for Tactic 3 and a certain percent for Tactic 4(Addresses statements 7,8 and 9 as the recruit will perform these processes independently).
- Question conclusion: Considering player A's alternatives in this scenario, what will be the best one to implement against his opponent? (Refers to statement 6 which concludes the question structure).

The listing of a probability is important to illustrate the player perception of capability according to his own internal scale. A similar situation occurs in the physician patient encounter as the patient receives his information in successful percentages. This is the only valid information about the decision making consequence that the physician can confidently share with this patient, i.e. successful procedures that he or the department performed.

3.5.11 Decision making attributes

In this research we have demonstrated how we can work through a framework and build a questionnaire based on a given scenario. Our case study refers to a set of parameters that are static in time, however, we know that real time decision making are dynamic. Dynamic decision making brings about a higher level of complexity when considering two main attributes that affect the expected payoff over time. The first one refers to the sequence or the order by which a decision is executed as there is effect from one decision to the next. A player's assigned values for performance characteristics which play an important role in quantifying the expected payoff of a certain decision in the game. Any change in the performance characteristics (physical, mental, or emotional) will affect the likelihood of success. For example, a sequence

of decisions have led to 6 points won back to back; this might change the confidence level of the player (emotional aspect). Another example would be that a sequence of decisions has exhausted the player, resulting in degraded level of performance (physical aspect). The sequencing attribute needs to be accounted for when considering dynamics in the game.

The second attribute that needs to be consider is the response learning curve to a certain type of decision in the game. The nature of the players is to maximize their performance thus they are constantly looking for the best response to a certain situation. The opponent will learn to adapt and perform better based on the frequency of decisions and their types, ultimately affecting expected payoff in future evaluations. The more an opponent will encounter the same play the better his response will be over time thus the play's expected payoff will decrease over time as well. This logic brings about the motivation for mixing strategies and tactics as there is a balance to determine when a certain play is profitable or not. These dynamics can be further examined using simulation especially when considering decision making affect over time.

3.5.12 framework summary

The research framework demonstrates how to analyze decisions in the game, overcome uncertainty and maintain relativity throughout the subjective assessment of specialist in the field. Once this framework is utilized any change to the analysis setup will demonstrate the effects at each level of decision making. This flexibility can prove to be quit significant in the recruitment process when evaluating the decision making capabilities based on a determined scenario. In the following section we have applied the research framework to analyze the decision making capabilities of tennis players in order to improve the Clemson Tennis Club team to have the best chance of winning. The objective of this collaboration is to understand how to mach players with their opponents based on their decision making capabilities in order to achieve the highest relative advantage. This case study resulted in elevating the players awareness, improved the players training program and provide a logical reasoning for creating a certain lineup.

3.6 Case Study: Decision Making Evaluation of College Tennis Players

Now, we would like to examine if a potential recruit is able to reach this logical reasoning when challenged to make a decision in a specific game scenario. We have created an appropriate survey using six tennis game scenarios. Each player was introduced to the evaluation logical reasoning with a consent form,

as well as a response/survey form to complete at certain points during the evaluation. This research and survey received institutional review board approval under protocol # IRB2015-365 at Clemson University, named "Human Performance Engineering and Decisions". The only identifiers were the department name and position title. The individual staff names were not recorded. Following the evaluation, each participant received a full analysis of the evaluation findings. Each participant also received a set of recommendations for improving his decision making capabilities in the future.

3.6.1 Creating evaluation questions

An evaluation question should contain a structure that imitates the actual player environment. In the introduction to the question (or series of questions), the recruit is first familiarized with the scenario. All performance characteristics of the players in the scenario are also described to the recruit. At this point, the recruit activates his imagination while he embeds himself in the described scenario. He imagines his opponent and the field of play, and he establishes a set of goals with which he is already familiar. From this point, the question should expose the available alternatives or possible decisions that the player could make in this scenario. The last part of this section is the question itself, where the recruiter can tailor to examine specific decision and its considerations of the potential recruit. This enables the recruiter to evaluate a player's ability to:

1. Identify performance characteristics that provide a relative advantage and their effect on the physical and mental aspect of the player's performance capability
2. Understand the relationship between performance characteristics, tactics and strategies in the game
3. Differentiate between successful tactics when considering player execution capabilities

Differentiation between executions of tactics could be addressed as localized decision-making. Successful execution of a certain tactic relies on the ability to control certain performance characteristics, resulting in less resistance from the opponent. These types of players can assess a specific situation and make a decision based on current capability. These players can make good decisions in a short time span, having exceptional execution abilities so that they can reach high level of performance.

A successful relationship between performance characteristics to tactics or strategies in the game could be addressed as short-term decision-making. These types of players can look at more than localized situations and make a decision according to a larger set of information. They can put together a game plan and be more effective in preserving energy than localized decision-making players. Players with an

effective short-term decision-making capability have a strong ability to tune themselves to certain situations and specialize in several skills. In high levels of performance, these players can potentially win any type of match.

Successful selection of game strategy reflects on the long-term decision-making capability. These player's are usually very consistent during high levels of performance and can play the game with a wide variety of skills. They can determine when and how to employ a strategy; thus, they can adapt to any type of situation and can predict many outcomes in the game. Such players may demonstrate the highest level of analytical thinking as they can look closely at specifics as well as considering the larger scheme in the game progression. Strategic players have the inert capability to make localized decision and short-term decision as well.

An evaluation form containing 42 scenario-based questions is created in order to examine the traits that are required to fill a certain position in the game (see appendix). As we mention earlier, these traits might depend on a subjective evaluation in order to establish the best fit for that position. Once the potential recruit has completed the evaluation form, quantitative and qualitative methodologies will be used.

The quantitative analysis section requires a system that would reveal the difference between a good decision maker and a superb one. In order to create this feature in the analysis, we need to be able to quantify each answer in a high variate scaling system. For example, for a multiple-choice answer, an exponential scoring response could be used in order to increase variability between the possible answers. Assuming we have a question to which we select an answer among five possibilities, each possibility will contain different level of descriptive information. An answer that is selected and contains irrelevant information will be of poor or inferior quality, thus its score should be the lowest. The range of answers contains many types of information and the scoring difference should be substantial in order to identify the player who considers the right type of information in the questioned scenario.

We propose the following scheme - the response's answers are assigned a quality level from inferior to superior, with a total of five possibilities. They are considered equally (spaced on a \log_2 scale, with the information score being given a value. Then, the difference between the remaining quality levels is expressed as 2 to the power of 1,2,3 and 4, thus the difference between the inferior level and the superior level is 30 points (see Table 3.9). This scale would generate a wider range of scores among the answers, thus providing an easier mechanism for detecting differences between the decision making levels among the players.

The qualitative section of the questionnaire asks the players to explain their reasoning behind their answers. This aspect allows the recruiter to extract more details about the way the potential recruit thinks.

Table 3.9: Sample grading scale with five possible answers

Answer Quality	
Inferior	0
Low	2
Average	6
High	14
Superior	30

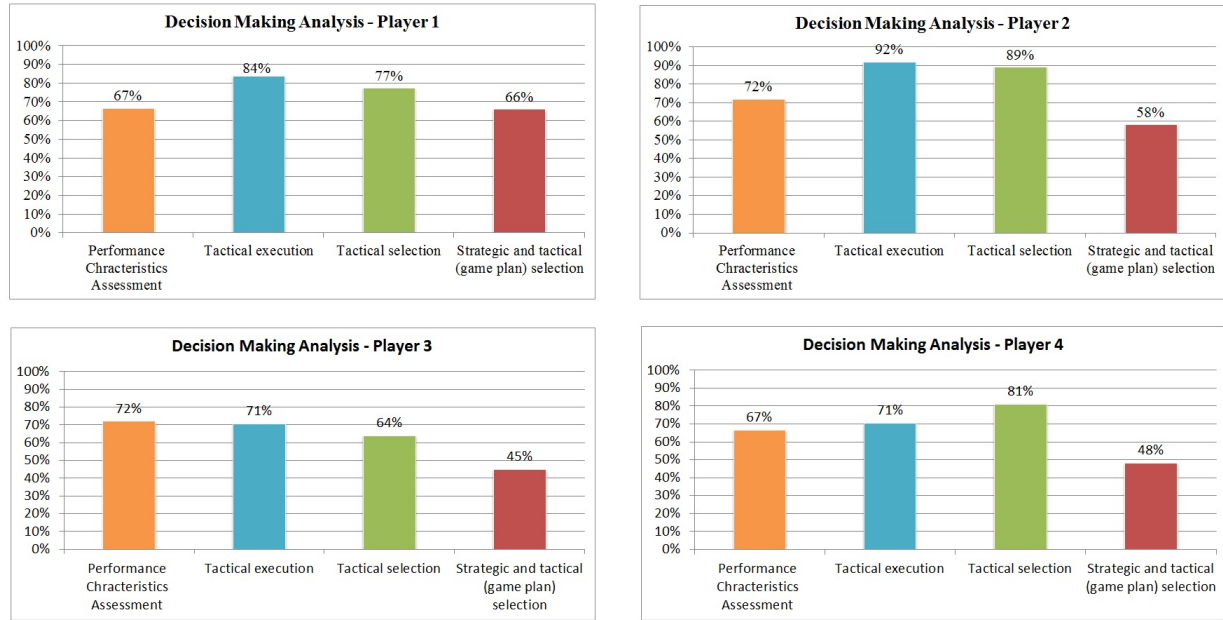
The recruiter can identify certain processing patterns and can evaluate the player's knowledge of the game.

From a current pilot study that is conducted with the Clemson Tennis Club team, college tennis players are presented an evaluation form. The form includes scenario-based expertise from former professional tennis players and tennis coaches, including an author of this paper. In this study the decision making capability of the players is challenged in an effort to identify strengths and weaknesses. Presented below are four players that demonstrate different decision making capabilities.

3.6.2 Analyzing the responses of a recruit - A Case Study

The 42 questions were divided into four grading sections: Performance Characteristics Assessment (PCA), Tactical Execution (TE), Tactical Selection (TS) and Strategic and Tactical Selection (STS). The percentage represents the success rate of the possible points earn from the available points in each section. Each player worked through the questionnaire at their own pace, and the graphs are the quantitative assessments of the questionnaire. When looking at the each player's decision making analysis, generic trends were captured. For player 3, we see how performance deteriorates as different aspects of decision making are being exposed. Player 1 presents the highest success in strategic decisions. Player 2 has the highest capability in tactical decisions. Player 3 understands performance characteristics but has a low level of strategic thinking. Player 4 excels in tactical decision making but poor strategic decision making. The meaning of these trends is very important as we conclude this section. Player 1 is an all around player, with high capabilities in every aspect of decision making. His average success is 73.5%. This player is consistent in his performance in the game. Player 2 has similar features as player one only he demonstrate higher level of capability. His average success is 77.7%. When compare to player 1 there are certain features of strength and weaknesses especially when considering game plan creation. Player 3 demonstrate lower level of performance then player's 1 and 2. He present the lowest success average with 63%. Player 4 present a better performance then player 3 but still lower then player 1 and 2. His success rate stands on 67.7%.

Figure 3.4: Summarized results from four different players



The qualitative aspect of the questionnaire reveals more subjective thinking when analyzing and selecting a certain type of decision in a specific game scenario. This section of the analysis can signal out character features in a player. The focus of the evaluation is to classify the ability of a player to interpret certain situations while providing reasoning for the selection decisions. From across the decision making sections, certain patterns of reasoning emerged. For example, player one's decision making capabilities are challenged when he needs to evaluate his opponent's reactions based on his own decision. His reasoning for his mistakes underlined this. Player two's reasoning is primarily based on response rather than initiative. This pattern might explain the gap between strategic thinking and tactical thinking. Difference in decision capabilities in the decision making space might suggest emotional constraints, especially when looking at confidence and consistent performance. Player 3 demonstrates a difficulty in identifying the relative advantage in the game, which is the essence of structuring a game plan. This is supported nicely in the quantitative data, such that when the challenge require different verity of cognitive logic from section 1 to 4, performance is decreasing and the player cannot adapt. Lastly, player 4 has difficulty in recognizing how performance characteristics affect the decision making space. This aspect means that this player will have the highest challenge with an opponent of high level of skill in his performance capabilities.

As a team manager, player profiling would aid in order to create the highest relative advantage in the game when considering which opponent to play with. When considering the quantitative results and the

qualitative information, matching of players with opponents should follow these guidelines. Player 1 should be matched with a player that has a few tactical alternatives and his game style should be very transparent. Player 2 should be matched with an opponent who demonstrates the same level of play or higher but does not hold high levels of strategic capabilities. Player 3 should be matched with an opponent with low tactical capabilities and who takes many risky shots in the game. Player 4 should be matched with an opponent who demonstrates low levels of skills and transparent physical and technical capabilities that would allow for specific tactical alternatives to be dominant.

3.7 Conclusions and Future Research

With many athletes possessing similar physical abilities that enable them to perform at a high level, the relative advantage can be found with the player's decision making capabilities. In this research we present a method to improve recruiting by evaluating decision-making in a potential candidate. Our framework creates a systematic way to form a recruitment evaluation, which could be tailored to any player position in the game. Using the results from the analysis of players on the Clemson Club Tennis team, we are enabling the recruiter to look at the decision-making capabilities of the player within his decision-making space. These findings give rise to a more analytic thinking when managing a sport team in order to achieve the highest relative advantage in the game.

Professional recruiters in the field have many issues to consider in a relatively short amount of time. Thus, this tool can help promote the recruitment process as it will create a structured framework that will sharpen the recruiter's ability to find the right player for the right position. The recruiter's ability to assess the decision-making type of the player will reduce the coach's uncertainty when he considers the player's performance in a certain game scenario.

This line of research can open the door for more examination of how performance characteristics take part in the decision-making capability of a player in the hope of achieving a higher level of performance. As we know how to scale a level of characteristics and evaluate the relative advantage, we can test these concepts further to quantify performance characteristics. Using computer simulation or similar tools, our approach in this research can help shape management setup and structure of an athletic program as its implementation will require a process of identifying, classifying and comprehending all aspects of human performance.

3.8 Acknowledgements

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3.10 Appendix

Table 3.10: Tactical data

Tactic	Benefit	Cost	Success Rate
1	1	2.35	0.95
2	1	2	0.7
3	0.67	2.35	0.95
4	2.5	2	0.5
5	3	1	0.6
6	3	4	0.8
7	2	2	0.8
8	6	1.35	0.2

$$E[T_1] = \frac{0.4}{2} \cdot 1.6 + \frac{0.6}{2} \cdot 4.5 + \frac{0.8}{2} \cdot 2.6 + \frac{0.2}{2} \cdot 1.5 = 2.86$$

$$E[T_2] = \frac{0.4}{2} \cdot (-0.1) + \frac{0.6}{2} \cdot 2 + \frac{0.8}{2} \cdot 0.9 + \frac{0.2}{2} \cdot (-1) = 0.84$$

$$E[T_3] = \frac{0.4}{2} \cdot 1.3 + \frac{0.6}{2} \cdot 4.1 + \frac{0.8}{2} \cdot 2.3 + \frac{0.2}{2} \cdot 1.1 = 2.52$$

$$E[T_4] = \frac{0.4}{2} \cdot (-0.7) + \frac{0.6}{2} \cdot 0.7 + \frac{0.8}{2} \cdot 0.2 + \frac{0.2}{2} \cdot (-2.2) = -0.07$$

$$E[S_A, T_1] = 0.2 \cdot 0.6 \cdot \{0.8 \cdot 0.4 \cdot 1.6 + 0.8 \cdot 0.6 \cdot 4.5 + 0.2 \cdot 0.8 \cdot 2.6 + 0.2 \cdot 0.2 \cdot 1.5\} = 0.38$$

Questionnaire Sample Questions

Performance Characteristics Assessment

- If I want to reduce my opponent reaction time, which characteristic would be the most beneficial to my performance?

Anticipation ,Endurance, Adaptability, Patience

Table 3.11: Tactical data when in play and its expected payoff

Tactic	Player 1			Player 2		
	Benefit	Cost	E[v]	Benefit	Cost	E[v]
T1—T5	2	5.33	1.6335	5.33	2	2.398
T2—T5	2	5	-0.1	5	2	2.2
T3—T5	1.67	5.33	1.32	5.33	1.67	2.53
T4—T5	3.5	5	-0.75	5	3.5	1.6
T1—T6	5	5.33	4.4835	5.33	5	3.264
T2—T6	5	5	2	5	5	3
T3—T6	4.67	5.33	4.17	5.33	4.67	3.33
T4—T6	6.5	5	0.75	5	6.5	2.7
T1—T7	3	4.33	2.6335	4.33	3	2.864
T2—T7	3	4	0.9	4	3	2.6
T3—T7	2.67	4.33	2.32	4.33	2.67	2.93
T4—T7	4.5	4	0.25	4	4.5	2.3
T1—T8	2	8.33	1.4835	8.33	2	0.066
T2—T8	2	8	-1	8	2	0
T3—T8	1.67	8.33	1.17	8.33	1.67	0.33
T4—T8	3.5	8	-2.25	8	3.5	-1.2

* Expected Payoff is calculated using equation 4 as well as Table 9

- If I want to take my opponent out of his comfort zone, which characteristic would be the most beneficial to my performance?

Aggressiveness, Precision, Agility, Alertness, Motivation

- If I want to reduce my unforced errors and go for high percentage shots, which characteristic would be the most beneficial to my performance?

Cleverness, Imagination, Self-Discipline

Tactical Execution Assessment

- Intro: Your opponent can anticipate your moves and he is highly adaptable, whereas you are more patient and have an advantage in your endurance capabilities.

Body: Our game analysis indicates that when you try to reduce your opponent reaction time, you have 70% of implementing this tactic. When you try to bring you opponent to the net you have 70% of implementing this tactic. When you try to approach the net and volley you have 70% of implementing this tactic.

Conclusion: Which tactic would you choose that will eventually earn you more points in the game

given your opponent characteristics?

Bring my opponent to the net, Approach the net and volley

Tactical Selection Assessment

- Intro: Your opponent can anticipate your moves and he is highly adaptable, whereas you are more patient and have an advantage in your endurance capabilities.

Body & conclusion: Given that you are mixing between reducing the opponent reaction time and high variety shots. Which tactics would you choose that will eventually earn you more points in the game given your opponent characteristics?

- Go for flat shots close to the net & hit the ball flat along the lines
- Serve Volley & go for the touch shot
- Approach and Volley & increase the shot height and depth
- Bring my opponent to the net & hit the ball with heavy spin to the court angles

Strategic and Tactical Selection Assessment

- Intro: Your opponent is highly aggressive and motivated whereas you are more precise, agile and alert to what is happening in the game.

Body & conclusion: Given that you are mixing between taking your opponent out of his comfort zone and changing court positions, which tactics will eventually earn you more points in the game given your opponent characteristics?

- Hit the ball with heavy spine for high bounce & Mix between power shot and floaters
- Flat shot deep in the court & Mix between rally from the base line and rally at the net
- Slice the ball for low bounce & Mix between short angle shot and high deep balls
- Hit the ball with heavy spine for high bounce & Mix between short angle shot and high deep balls

Chapter 4

Improving a Tennis Player's Shot Selection by Accounting for Fatigue

4.1 Abstract

Performance characteristics (PC) play a vital role in the decision-making process. These PC's can be articulated by the player's physical, emotional and mental states, as well as the environmental conditions in certain situations. Although the relationship between these PC's and decision-making are not yet known, this study aims to specifically address how fatigue impact the player performance. The research evaluates the tennis player ability to update his decision-making due a change in his physical capability. A simulation model is developed to help players test various decision-making patterns in order to improve their decision-making logic in the game. An optimization scheme utilizes the simulation model to find the best decision-making pattern for each player. Our research findings demonstrate that at some point the player will select a lower risk target under increasing levels of physical exhaustion and select a higher risk target once recuperated. The study present a predicted player performance improvement of 18%, 11%, and 4% at the amateur, intermediate and advance skill level of play.

4.2 Introduction

The dynamics of performance is very challenging to define when considering the physiological, psychological and emotional capabilities. It is rational to assume that when energy is consumed from the body,

the capability of the player should decrease. In Lyons et al. (2013), there is an increase in the player accuracy, for experts and amateurs, as the players reached 70% of their energy use (fatigue). However, both player types experience a degradation in their accuracy as they reached 90% of their energy usage. One explanation for this phenomena is due to a player's practice experience, as players of all levels will spend most of their practice in a physical range with proximity to what was recorded as the 70% mark. On the other hand, players spend a limited amount of time practicing at the 90% level as it is also poses an injury risk. In Ferranti et al. (2001) the players performance was significantly higher when given 10 seconds recovery than 15 seconds recovery. Logically, if the player has more resting time between shots, he should perform better but, as illustrated, this is not the case. Furthermore, in a review made by Kovacs (2006), the physical condition of optimal performance is shown in various aspects for the tennis player, including flexibility, power, speed and agility, strength, and fatigue.

It is demonstrated that too much or too little stimuli will not produce high level of performance when considering the physical conditioning. Moreover, the same line of thinking can explain the emotional and the cognitive features of the player as well. It is also evident that there are competing factors such as accuracy vs. power, recovery time (rest) vs. endurance, fear vs. excitement, and planning vs. improvisation. The key to maintaining a high level of performance under changing condition lies in the decision-making capability of the player. In the next section we will look into the decision-making features and investigate how they play a role in the decision-making process. Next, we will discuss our research approach and tools. Following this, we will present our data collection scheme and explain our analysis method. Next we will address the simulation model and its application in educating tennis players, discuss our findings and their implications, and conclude with a discussion to complete this research paper.

4.3 Motivation and literature

There are many factors that impact the player performance ranging from emotional desires such as pleasure and satisfaction to physiological capability such as flexibility and technique. These features are taken under consideration in the decision-making process as they are dynamic in nature, and may change every time the player starts a new tennis session. In this research, a game setting is proposed with an objective of accumulating as many points as possible. The game settings take under consideration time limitation, feedback, and past experience when evaluating the ability of the player perform and make decisions. The study demonstrate how a characteristic like fatigue affects a player's performance, and offer insights into strategies for improving performance and decision-making when faced with fatigue.

With no time limitation, the majority of the population will behave consistently according to principles of rationality (Association of American Publishers Professional and Scholarly Excellence Award, Glimcher (2004)). Time pressure increasingly challenge the decision performance as it affects different individuals to different extents, but the general trend remains consistent: with reduced time to react, individuals demonstrated less ability to discern important information before making decisions, Glimcher (2004). The analysis of decision times revealed that the existence of the time constraint, not time insufficiency, causes performance degradation. It also caused participants to adopt simpler strategies instead of analyzing and making decisions adequately.

Feedback to a decision may change the process of making decision (according to Zeelenberg (1996)). The results of his experiments show that the anticipation of regret can promote risk-averse as well as risk-seeking choices. This finding contradicts the claim that the anticipation of regret only results in risk-aversion as suggested by Kardes et al. (1994). Feedback comes at the end of the decision-making process but bias comes in the beginning. According to Evans (1989), decision-making bias is when previous events or experiences, as well as individual personality traits, influence future decisions. In a different situation, bias can lead someone to make riskier decisions due to a success streak with their choices. A rational decision maker is someone who demonstrates consistent choices over time, however, humans, although demonstrate principles of rationally, demonstrate bias over time. One interesting way to trigger bias is through the presentation of information. In the study of Martino et al. (2006), subjects were shown the same problem but in two versions of presentation: one with a positive frame and one with a negative frame. Their research showed that under different presentations, the tendency to take risk is significantly different.

Perhaps the most powerful influence lies with past experience or an embedded habit (according to Arts et al. (1998))). In their study they exposed the participants to decision-making alternatives given ample time to gather the necessary information. They showed that, with repeated trials or gained experience, participants learn to isolate certain cues in the presented information, thus executing their decision faster and more efficiently. This repeated knowledge empowers the participant to develop insights that bypass certain decision-making processes and enables the participant to deal with complex situations more quickly.

decision-making is a dynamic process as there are competing factors that assume new meaning with each passing moment. Specifically in tennis, the physical, emotional and mental capability are put to the test in every single point as the player is the sole decision maker, aiming to win the game. In the research of Kovacs (2006), the game demands various elements that are customize to each experience. The game is unpredictable in its point length, shot selection, strategy, match duration, weather, ball speed, distance covered by the

players, and various types of player characteristics that change throughout the match. Furthermore, Shvornin and Taaffe (2014) offer an analysis scheme where performance characteristics are linked to create a profile of the player capabilities. Once a profile is created for a player or a team, appropriate strategies and tactics could be generated to maximize performance in the game.

Although we have yet to understand various types of performance characteristics impact on the decision-making process, fatigue is considered extremely critical when considering injury prevention, performance preservation, and play a vital rule in decision-making. According to Carpenter et al. (1998), Mayers et al. (1999), and Murray et al. (2001), fatigue affect the player mechanics, reducing ball velocity, limiting large range of motion, reducing proprioceptive ability, increasing response time, reducing sensation of joint movement, reducing skeleton rotation, and reducing emotional and cognitive functioning. According to Linossier et al. (1997), Hargreaves et al. (1998), Pearcey et al. (2015) and Bachasson et al. (2016), the metabolic and physiological functioning such as duration of recovery, duration of the intensity of work, and the regulation of physiological strain during intermittent exercise is also reduced by fatigue. According to Bouaziz et al. (2016), fatigue cause a continuous degradation of phosphocreatine, thus placing greater demand on glycogenolysis and glycolysis that increase the level of acid in the muscle. If exercise is undertaken with limited rest periods for more than a few days in a row, it can lead to dangerous over-training syndrome.

Ferranti et al. (2001), suggest that a decrease in running speed results in inaccurate stroke preparation, leading to a decrease in stroke speed (performance), as well as possible stroke intention (avoiding errors as opposed to hitting winners). According to Davey et al. (2002/2003) as well as reaffirmed by Lyons et al. (2013), shot accuracy is reduced by as much as 81% when a tennis player is nearing volitional fatigue. After the fatiguing test employed in their study, four minute side to side forehand and backhands drill with a 40 second rest period until volitional fatigue was achieved, they demonstrated a 69% deterioration in hitting accuracy of ground strokes and a 30% decline in accuracy of the service to the right hand court. In addition, it has been reported that after a two hour strenuous training session, an increase in ground stroke errors during defensive rallies and an increase in errors on first serves were observed.

Fatigue in these experiments is not representative of the physiological strain encountered during a match setting, nor of most practice drills. This artificially induced fatigue state will lead to high lactate levels that are not typically seen in tennis matches. As tennis competition has average points lasting less than 10 seconds, with rest periods of approximately 20 seconds between points and 90 seconds after every second game, the physiological variables are unlikely to lead to a large accumulation of lactate. Thus accumulating lactate levels are not a major cause of fatigue in tennis match play.

4.4 Methods

While there is evidence for performance degradation due to fatigue, it is less clear how fatigue impacts the decision-making process, especially when considering risk taking. Logically, if the performance level of the player is reduced as fatigue comes into play, the player should select targets that require less effort. This means that the player should accommodate his performance degradation with reducing his risk taking shots in the game. In order to test this theory, we created a drill that test how target selection might change due to fatigue impact on shot accuracy in a tennis drill.

The study is internally funded by the Watts Family Innovation Center (WFIC) creative inquiry program. It received its Internal Review Board (IRB) confirmation number (e.g. IRB2016-249) in 10/6/2016. Our team encompass five undergraduate researchers, one graduate researcher and a faculty adviser. This study collaborates with the Clemson University club tennis team and coordinates its activity based of the team availability.

4.4.1 Participants and testing site

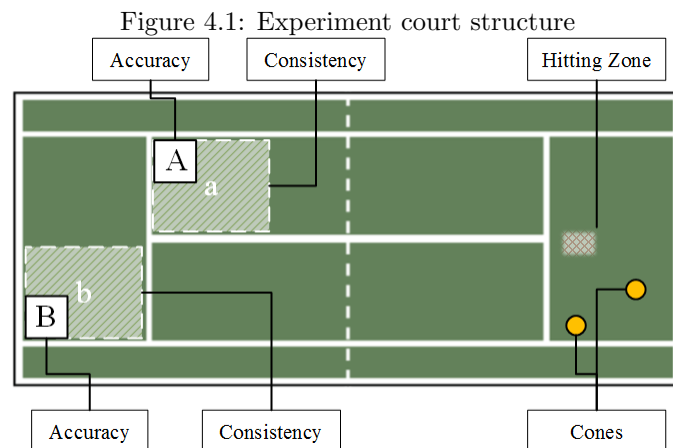
This study included three college players who are actively training in the Club Tennis Team program at Clemson University. The players are males, ages of 19.8 ± 1.2 years. The tennis players experience ranges through 5 ± 2.2 years. The players train four times a week roughly around two hours per training session. The players participate in an amateur level league between schools, organized by clubs of different schools in the country, unlike the formal division league which is registered with the Atlantic Cost Conference (ACC) and play in the National College Athletic Association (NCAA) games. The players also present three levels, amateur, intermediate and advanced performance skills.

The experiments were hosted in the indoor courts at the evening sessions of practice between 6:00 and 9:00 pm. The courts are standardize according to the NCAA specifications and made out of Asphalt Cushioned Surface. The courts meet American Sports Builders Association (ASBA) requirements for safety regulations. Lighting is uniform and glare-free and is provided from six direction to each court. In winter, the facility temperature is between 13-17C (55-62F), and in summer, the temperature of 23-35C (75-95F). Humidity is between 55-60% and noise do not exceed 45 dB according to the facility specification.

4.4.2 Experimental design

The study used a similar design structure such as presented in Ferranti et al. (2001), Davey et al. (2002/2003), and Lyons et al. (2013). Informed consent were collected as required according to the study IRB protocol. Medical approval is required from all athletes who participates in a club sport activity thus naturally accommodates the IRB protocols. Each participant was made fully aware of the purpose of this study and participated on a voluntary basis with the option to steer away from the study at any time. The study requires one session from each participant that includes baseline measurements (moderate fatigue, and intense fatigue) and a decision-making game.

The court setup takes into account two different type of shots as each one have a purpose in the experiment as you can see in Figure 4.1. Target A is located at the edge of the service box and require a delicate control shot of slice type, using a continental grip (recommended). Target B is located at the edge of the baseline and the single court boundaries and require a forehand shot cross court. The distance from the center of target A to the hitting zone is roughly 42 foot and the distance from the center of target B to the hitting zone is roughly 60 foot. Both targets have the same size and shape (6.56 x 6.56 squared foot). The consistency zones have the same size and shape (13 x 13 squared foot), and they include the accuracy zones in the drill. The hitting zone area is located in the center of the court slightly closer to the service boxes. This means that the serving ball actually bounce near the end of the service boxes allowing this shot to be consider an approach shot thus making the two targets effective in a real match (depending where the opponent is located). The two cones next to the hitting zone mark the movement area between shots.



The objective of this study focuses on decision-making thus its structure relays on former studies such as Davey et al. (2002/2003) and Leyons et al. (2013) when it comes to performance degradation due to

fatigue. Players will first warm up for at least 15 minutes and get familiarized with the targets and the shot recommendations, although they can use their own comfort shot style. The players will only hit forehand shot for the duration of the drill. In the moderate session the players will hit 100 balls to target A following by 100 balls to target B, throughout the drill the players will be required to minimize their movement so they do not have to move between shots. In the intense portion, the same setup will occur only the player will have to mimic a game movement between shots. After each shot from the hitting zone, the players will move as close as they can to one of the cones. If they are hitting to target A, they will move backwards and if they are hitting for target B they will move sideways.

The last session includes a game where the players can make a decision and select the target they want to aim at. Similar to the intense settings, the players will have to move between shots, however, they will hit 141 balls which will take more play time. The drill will take roughly six minutes to perform. This play time period resembled the time phase for achieving high levels of fatigue as discussed in Davey et al. (2002/2003) and Leyons et al. (2013).

4.4.3 Data collection and scoring

The base line measurements (moderate and intense) will take into account the amount of shots that were accurate (hitting target A and B), the amount of shots that were consistent (hitting the consistency zones) and the amount of shots that were out of court or hit the net. Each player will be fitted with a bio-sensor (empathica) device which presents real time information such as heart rate, body temperature, hitting acceleration, and stress levels.

In the baseline session there is no scoring but only a reflecting percentage for hitting the target and the consistency zone. These two sessions enable us to show the player how his performance degrades when the drill intensity changes and fatigue starts to build up. In the game session, scoring is determined in the following way. For each consistency zone that the player hit, he will receive one point. Hitting target A will earn the player two points while target B will earn the player four points (double in benefits).

The goal of the player is to achieve the maximum score in the game, which means that the player should get as many points as he can in the allotted amount of shots.

4.4.4 Experiment equipment

- The Empatica 4 or in short E4 device, is a wearable body sensor that sits on the human wrist. It has four sensors that measure blood volume pulse (BVP), electrodermal activity (EDA), infrared thermopile

and three axis accelerometer. These sensors provide information regarding heart rate, stress levels, skin temperature and motion in space. The device is blue tooth and wireless and is used to record body function over the duration of the experience. The data is uploaded via WIFI and downloaded as a csv data file. The photoplethysmography sensor measures BVP, from which heart rate (HR), heart rate variability (HRV), and other cardiovascular features is derived. The EDA Sensor measures the sympathetic nervous system arousal to derive features related to stress, engagement, and excitement. In recent studies, Hernandez et al. (2015), Bidwell et al. (2015), Picard et al. (2015) and Callaway et al. (2015), significant relationships were detected between stress levels and heart rates to various medical conditions. Currently this device is under a clinical trial for detecting seizure and bio-markers in epilepsy, Van Dooren et al. (2012).

- The Lobster Sports Elite Liberty Tennis Ball Machine is used in our experiment. The machine can produce ball speeds from 20 mph up to 80 mph and offer spin control which can be adjusted for both topspin and backspin and at different levels. The large ball capacity can hold up to 200 balls and battery last for four hours at most. The machine also offer full corner-to-corner random oscillation and up to 50-degree lobs to practice overheads.

The empatica E4, was design to measure resting heart rate (not while playing a game), thus there is a constant deviation from real heart rate. Temperature measurement reflects skin temperature and not internal body heat level, which might create different behavior due to sweat (the body cooling itself utilizing its skin).

4.5 Results and discussion

In this section we will examine specific aspects of the experiment. First, we will address the design of the drill as it fosters the link between fatigue and decision-making. We will continue to examine the physiological trends that occur and link these changes with the ability of the player to perform (hitting the target). Lastly, we will address the game structure and the decision patterns that it produces.

The statistical testing, using MinTab17, was conducted to determine where statistically significant differences or trends existed between participants or between groups of shots (representing periods of time during the experiment).

4.5.1 Drill design validation

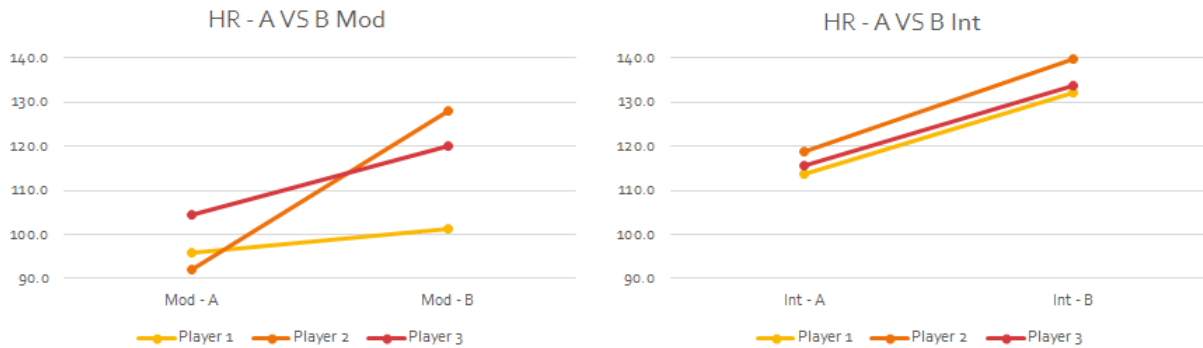
The drill designed intend that Target B would be more difficult to hit than Target A, and that the Intense level of physical engagement would exert more energy from the player than the Moderate level of physical engagement. In order for the drill to achieve what is intended, we test the following hypotheses:

H0: Hitting the ball to target B, on average, will not require higher levels of physical engagement (HR, EDA, ACC, Temp) from the player than hitting the ball for target A.

H1: Hitting the ball to target B, on average, will require higher levels of physical engagement (HR, EDA, ACC, Temp) from the player than hitting the ball for target A.

In order to test this hypotheses we look into our biodata. In Figure 4.2, we can see the drill settings trend of heart rate average level when comparing target A to target B. The analysis of variance (ANOVA) compares between the three players average heart rate when hitting at Target A and Target B, when considering the moderate and intense levels of physical engagement. The intense drill setting presents a significant difference in heart rate levels when hitting for target A as opposed to target B. From the intense portion of the drill, with $p\text{-value} = 0.002$, we can conclude that the null hypotheses can be rejected, thus target B consumes more energy then target A when considering heart rate level.

Figure 4.2: Heart rate comparison between targets and drill intensity



In the Table 4.1, we can see that differences between target A and B were significant when considering heart rate and shot acceleration at the intense physical level. Since the rest of the measurements have received lower significant results (i.e. there was no difference on average between players in these settings), we can conclude that they are the same. In conclusion, target B have demonstrated higher level of physical

engagement than target A, confirming that the drill achieves its design objectives. At this point, we can conclude that the null hypotheses can be rejected, thus target B requires higher levels of physical engagement than target A when considering heart rate and shot acceleration level.

Table 4.1: Statistical differences between targets in moderate and intense drill settings

Physical Level (P-value)	Heart Rate	Electrodermal Activity	Shot Acceleration	Skin Temperature
Moderate	0.095	0.630	0.111	0.765
Intense	0.002	0.128	0.047	0.691

While the biomarkers, presented in Table 4.1, could have some effect on physical engagement and fatigue (and ultimately shot accuracy), the only consistent measure is heart rate. So as we move into the simulation/optimization section, we will focus our attention on this measure.

Looking further into the drill design, we need to assess how the bio-markers rate differ across the drill physical level when hitting to Target A and Target B. The following hypotheses is defined as:

H0: Hitting the ball to target B, on average, will not cause higher heart rate increase than hitting the ball to target A.

H1: Hitting the ball to target B, on average, will cause higher heart rate increase than hitting the ball to target A.

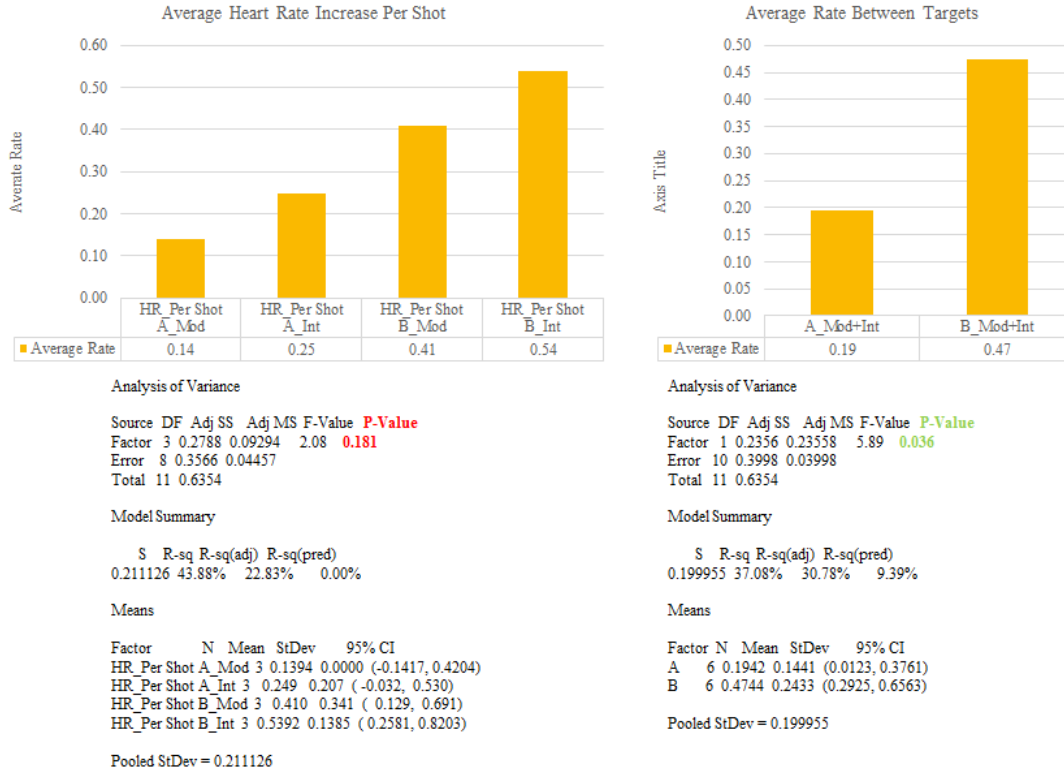
In order to test this hypotheses we look into our biodata and continue to examine heart rate, shot acceleration, stress level (EDA) and skin temperature. In Figure 4.3, a breakdown of heart rate elevation per drill settings is shown in the left side. The rate of change is calculated utilizing the following formula:

$$HeartRateIncreasePerShot = \frac{Max_{HeartRate} - Min_{HeartRate}}{TheNumberofShots} \quad (4.1)$$

This calculation is done for each player thus we receive a table with 12 entries. As you can see, the drill settings demonstrate a trend as, on average, heart rate level increase the most in the intense section when hitting the ball to target B. On the right side, you can see the difference in heart rate increase between hitting to target A and hitting to target B per shot on average. This graph includes both the data from the moderate and the intense level of physical engagement.

When testing for differences in heart rate increase within each drill setting, we could not reject the null hypotheses thus across the drill settings there is no justification for significant change in increase rate.

Figure 4.3: Differences in heart rate based on drill settings



However, when looking at the two different targets, there is statistical evidence that the increase of heart rate is significantly higher when hitting the ball for target B, thus we reject the null hypotheses. In the Table 4.2, the summary of our statistical testing is presented across the bio-markers which was recorded in the drill.

Table 4.2: Statistical testing: differences in bio-markers rate of change

Bio Marker (P-value)	Drill Settings	Target Comparison
Heart Rate	0.181	0.036
Shot Acceleration	0.156	0.259
Stress (EDA)	0.158	0.246
Skin Temperature	0.699	0.646

From Table 4.2, we can see that across the drill settings there is no significant change in rate when considering the recorded bio markers. Due to insufficient statistical evidence we fail to reject the null hypotheses, thus we can't determine that a bio marker is producing a different result or value based on drill settings.

When comparing between targets, heart rate is the only bio-marker that demonstrates a significant

change. For this bio-marker, we reject the null hypotheses and conclude that there is significant difference in the rate of change when hitting to Target A and when hitting to Target B. The rest of the bio markers show lack of statistical evidence when considering differences between the two targets thus we fail to reject the null hypotheses and conclude that the bio-markers rates of change do not produce differences in results when compared between targets.

4.5.2 Player bio-markers - first 50 shots vs. last 50 shots

From our drill validation we have concluded that hitting the ball to Target B will increase heart rate more than twice as fast when compared to Target A. In this section we take a closer look at the trends in the bio-markers data for intense drill setting only. Since we only have 100 shots, we have divided the data to look at the first 50 shots and the last 50 shots.

In Table 4.3 we can see that when fatigue comes into play, the heart rate of the players increases over the duration of the drill in both targets. Beside heart rate, the rest of the bio-markers do not present significant trends, however with more data (and a larger sample) it is expected that the average sore per shot and shot acceleration will decrease while skin temperature and stress will increase.

Table 4.3: Statistical testing: average bio-marker trends in target hitting

Description	Score Per Shot	Heart Rate	EDA	ACC	Temperature
Target A Response - First 50 shots	1.08	110.76	18.19	0.75	33.79
Target A Response - Last 50 shots	0.91	121.11	15.6	0.77	33.66
Percent change	-16%	9%	-14%	3%	-0.4%
p-value	0.476	0.039	0.354	0.842	0.933
Target B Response - First 50 shots	1.01	123.85	21.94	1.01	33.97
Target B Response - Last 50 shots	0.88	146.46	22.39	0.98	34.64
Percent change	-13%	18%	2%	-3%	2%
p-value	0.468	0.003	0.898	0.749	0.624

To strengthen these bio-marker changes over time, more players are required as the data that we currently have, relates to a small sample of three players. Although statistical justification for all bio markers do not exist at the moment, the trends reflect the behavior observed in reality and strengthen the drill design validation.

4.5.3 Accuracy and consistency in different drill settings

As was noted in the prior section, the average score per shot appears to decrease for the second 50 shots, and we believe the result is not statistically significant due to the small sample size. However, it

motivated us to consider another test to examine the role of drill intensity on the ability to perform (i.e., hit accurate shots). In fact, we would expect to see a difference in the player's ability to hit the target. The drill design allowed for two areas around each target to assess a player's ability (as described earlier). The consistency area is bigger and allow the player to know that his shot was close to the target, thus making him aware that the shot was good but not perfect. The accuracy zone is smaller and provides a positive feedback that the shot was perfectly executed. The following hypotheses is put to the test:

H0: On average, a player will not have less success in hitting a specific target, when comparing the intense level to the moderate level.

H1: On average, a player will have less success in hitting a specific target, when comparing the intense level to the moderate level.

In Figure 4.4, the players hitting average for accuracy zone and consistency zone is shown when considering the moderate drill settings and the intense drill settings (Note that, for the purposes of this hypothesis test, a shot in the accuracy zone is also counted as being in the consistency zone. This allows for a better description of a player being "consistent" for the scoring in this test). The intense drill setting is more affected by fatigue, however this trend needs to be statistically examined.

Figure 4.4: Accuracy and consistency in the moderate and intense drill settings

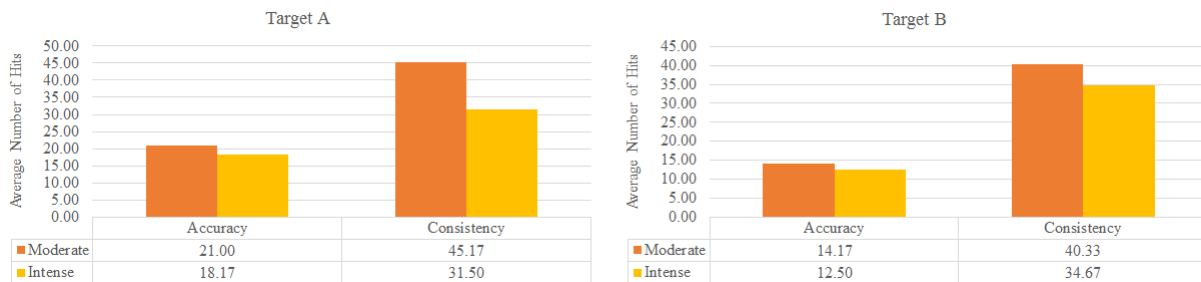


Table 4.4, summaries the statistical testing for each comparison demonstrated in Figure 4.4. While the trends of performance are observed in this study, as well as supported in the literature, statistical significance was found in the consistency zone for Target A. The players, on average, found it more difficult to hit Target A's consistency zone at the intense level, than at the moderate level. We can reject the null hypothesis and conclude that the player will have less consistency in hitting targets over the duration of the drill for hitting towards Target A. We do believe that more of these tests would return significance results

with a larger sample size. However, we cannot conclude that at this time.

Table 4.4: Statistical testing: accuracy and consistency differences

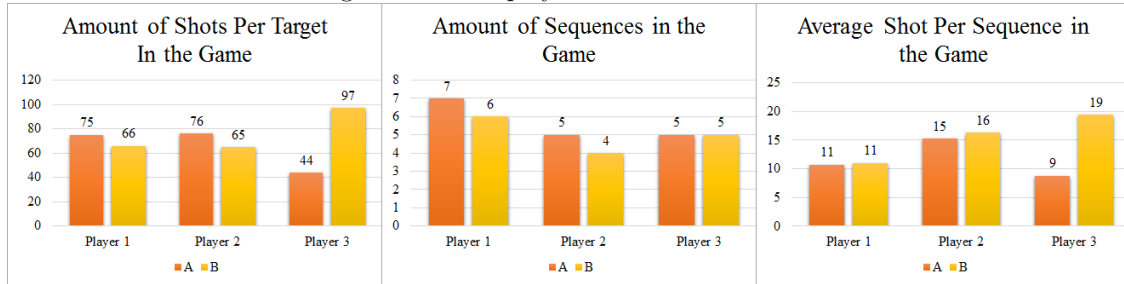
Drill Type	Target A Accuracy	Target A Consistency	Target B Accuracy	Target B Consistency
p-value	0.381	0.004	0.587	0.105

In the next subsection we will focus on analyzing the game structure and the decision-making patterns of the players.

4.5.4 The game structure and decision-making patterns

In this portion of the analysis we examine the players decision in the game. We looked into how well they performed under stressful conditions, and how well they made decisions to change between targets A and B. That decision could be unique by player, based on their ability to hit each of the targets, thus decisions pattern could be different among the players. The summarized decision data includes the amount of shots per target, the amount of target changeovers (sequences), and the amount shots per sequence in the game. Figure 4.5, presents these elements in three graphs and provides a comparison for each player in each element.

Figure 4.5: The players decision breakdown



When testing for differences between the players, the evidence found in the statistical testing (ANOVA) concludes that there is no significant difference between players when considering the amount of shots per target (p-value = 0.406), the amount of sequences per target (p-value = 0.492), and the average shot per sequence per target (p-value = 0.268).

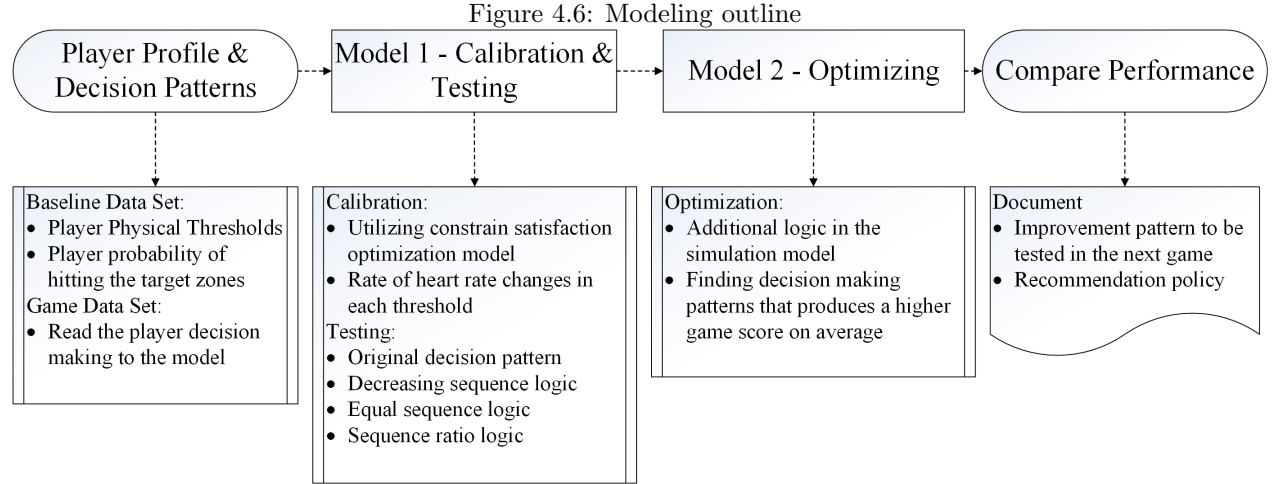
The three players have levels (independent of each other) at which they can perform, and for this reason, it is important to evaluate decision-making on a player-by-player basis. This will be fully explored in the next section when the simulation-optimization modeling framework is introduced.

4.5.4.1 Decision-making patterns conclusions

The evidence presented here confirms that the players each respond to the drill with their unique decision making pattern. Once these patterns are analyzed, the risk taking nature of the players can be evaluated as well as be reflected in the score. In order to assess this part of the decision-making process, a simulation model was created and will be addressed in the following section.

4.6 Simulation and optimization modeling

In this section, we employ a simulation model to examine a player's shot selection sequence (i.e., decision-making pattern) with a goal of achieving a higher score in the game used in the prior section. Upon completing the baseline drill and the game, the player's data is entered into the simulation in order to customize its feedback according to the player's performance profile. Here is an outline of the performance improvement methodology:



In the following subsections, we will follow the outline described in Figure 4.6 and demonstrate the data outcomes from our drill when comparing results between our three players. The ARENA simulation software package (version 15) as well as its built in optimization tool OptQuest, were used to conduct the modeling and analysis.

4.6.1 Players profile

From reviewing data in the drill from the prior section, three heart rate threshold levels have been assumed. The threshold levels are determined by the maximum heart rate that the player reaches in each module of the drill. In Table 4.5, we can see the thresholds detected from the baseline drill for each player. The three players exhibit different heart rate levels, however note that lower heart rate by itself does not imply better performance. Different players operate under different body conditions. For example, player two had a higher resting heart rate than player one, however his performance (game score) was better than player one.

Table 4.5: Heart rate thresholds per player

Player	Low Threshold	Medium Threshold	High Threshold
Player 1	123.3	138.5	150.2
Player 2	142.5	148.1	170.5
Player 3	118.6	142.4	149.9

Since these thresholds were detected in different drill setups, the probability of hitting the accuracy zone and the consistency zone can easily be attained from our base line data. In Table 4.6, we can look at the breakdown of success in each threshold. Since each player is unique, generic trends in shot success rates across players do not necessary apply. For example, the accuracy probability for Target B, decreases with an increase in heart rate threshold for both players one and two. On the other hand, player three has a higher success probability for the accuracy zone of Target B in the medium threshold as opposed to the lower threshold. This means that the player was more accurate at a higher level of physical engagement than in a lower one. In this section of the analysis we address the target zones as mutually exclusive in order to associate the adequate success probability.

Now that we have the player profile, we move to the next section were the simulation model is describe in more details.

4.6.2 Simulation model structure

Once the profile of the player is uploaded into the model, a target acquisition iteration begins. In each iteration, the decision of the player is uploaded and the score is calculated according to two parameters: the player's current hear rate status and the probability of success that is associate with that threshold. In the simulation, the player can move from one heart rate level to another after performing a shot, based on the amount of heart rate change that the player exhibits for that particular shot. In Figure 4.7, a simplified

Table 4.6: Probability of success per heart rate threshold

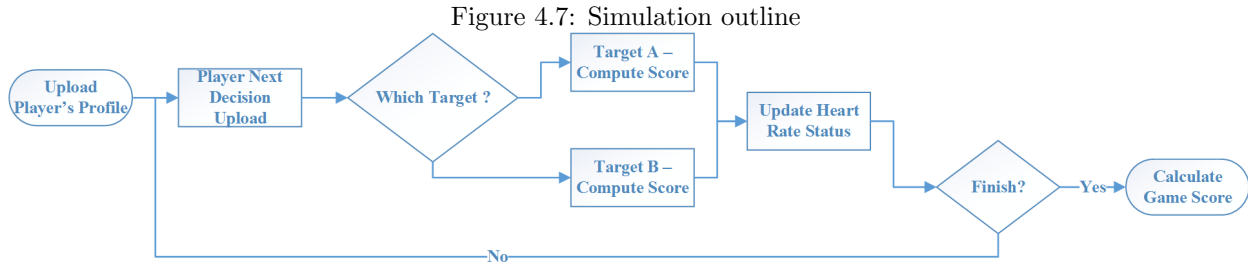
Player 1	Threshold	Target A Accuracy	Target A Consistency	Target A Misses	Target B Accuracy	Target B Consistency	Target B Misses
	123.3	42%	46%	12%	22%	52%	26%
	138.5	38%	60%	2%	16%	62%	22%
	150	30%	34%	36%	12%	62%	26%
Player 2	Threshold	Target A Accuracy	Target A Consistency	Target A Misses	Target B Accuracy	Target B Consistency	Target B Misses
	142.5	42%	48%	10%	32%	54%	14%
	148.1	30%	42%	28%	30%	38%	32%
	170.5	26%	20%	54%	18%	28%	54%
Player 3	Threshold	Target A Accuracy	Target A Consistency	Target A Misses	Target B Accuracy	Target B Consistency	Target B Misses
	118.6	52%	44%	4%	24%	64%	12%
	142.4	48%	50%	2%	46%	44%	10%
	149.9	36%	34%	30%	34%	46%	20%

Note that the game scoring is as follow:

Target A: Accuracy = 2 points, Consistency = 1 point, Miss = 0 points.

Target B: Accuracy = 4 points, Consistency = 1 point, Miss = 0 points.

version of the model is presented to illustrate the flowchart of processes in the model.



At this point, the profile and the decision-making list of the player is addressed in the model, however there are some gaps when customizing the model to reality. As described earlier in section 4.4, each player will have his own heart rate trend as he plays the game. This is why we need to calibrate the model to reflect unique characteristics of each player.

4.6.3 Model calibration to player profiles - model 1

The game structure is different from our baseline drill thus in order to fit the model to the player we need to find the right heart rate trends that will reflect the approximate score of the player when executing the same decision-making patterns. In order to figure out this calibration we follow a constraint satisfaction model. The objective of the model is to find the heart rates trends that will produce a simulation score

approximate to the real score of the player in the game. Utilizing an optimization framework (OptQuest) the model follows the following scheme:

Objective: Maximize Score

Subject to: Score must be less than the player's achieved score in the drill

- As threshold level increase heart rate elevation from hitting Target B will decrease
- As threshold level increase heart rate reduction from hitting Target A will increase

For the mathematical notation and heart rate parameters produced by the model, please see the appendix. Upon completing this customization we have a simulation model that approximates the player heart rate conditions in the real game. From this point, any change to his decision-making pattern (or shot selection sequence) will result in a different score, as it will change his physiological status in the game, which will alter his performance. This environment will allow the model to test various patterns of decision-making while predicting the expected and compare the resulting score.

Each player's game data contained three main characteristics: number of sequences, number of shots in each sequence, and the target of the sequence. Data analysis of the game data revealed that a player will create a sequence to Target B (worth more points) until fatigue impacts the player performance to a certain point. At this point the player will be motivated to create a new sequence to Target A, in order to increase shot success and increase their score, even though the target is worth fewer points. This also allowed the player to recuperate and reduce his heart rate to a point when he felt comfortable again to create a sequence of shots to Target B. This pattern is consistent among the players in our study (please see section 4.5).

The players only played the game once, thus only one score was captured during this study. This score by no means represents the long term performance of the player in the game as his performance will likely change each time he plays the game. The advantage of the simulation model is in replicating the player performance in order to infer an expected performance level over the long run. In Table 4.7, we can see that the real score of the players is approximated as if it was a long term estimation. The simulation included 30 replications that included the player decision and heart rate thresholds (historical data) as well as the rate of change in heart rate for every threshold (OptQuest data). The half width help us to identify the range of the true average of performance. For example, with 95% we estimate that the true average score of player one's performance will be between 154 and 167 (when rounding the score).

In the low, medium and high threshold rates, we can see the difference between heart rate changes per shot for Target A and Target B. Since all the players start at a common heart rate (103.5), it will take a sequence of seven shots to Target B, for player one to move from the low threshold to the medium threshold.

Table 4.7: Results from calibration of the simulation model

Player	Real Score	Low Threshold	Med Threshold	High Threshold	Sim Score + Half Width
Target A Rates	161	-0.52	-0.52	-1.1	161 ± 6.11
Target B Rates		3.2	1.52	1.5	
HR Threshold		123.3	138.5	150.2	
Player 1					
Target A Rates	188	-0.83	-1.6	-1.7	188 ± 5.47
Target B Rates		2.57	1.5	0.6	
HR Threshold		142.5	148.1	170.5	
Player 2					
Target A Rates	249	-0.33	-0.55	-1.71	249 ± 5.95
Target B Rates		2.9	1.03	0.8	
HR Threshold		118.6	142.4	149.9	
Player 3					

The same logic applies for a sequence of shots to Target A which will reduce his hear rate level from one threshold to another. It is important to notice how the rates of heart rate, change from one threshold to another. For example, a shot to Target B at the low threshold level will increase the heart rate level more then a shot at the high threshold level. The same can be said on a shot for Target A, only instead of increase in heart rate the player will experience a decrease in heart rate.

4.6.4 Testing decision-making logic

When receiving feedback from the players, often the players admitted that they should have taken more time to recuperate after a long sequence to Target B. This means that they have started a sequence to Target B at a higher heart rate condition, thus lowering their probability of success in the process. In this section we test three different patterns:

- Decreasing number of shot per sequence when alternating from Target B to Target A (Org)
 - Player 1 - 34, 21, 13, 21, 11, 12, 8, 2, 4
 - Player 2 - 20, 23, 18, 22, 15, 19, 12, 10
 - Player 3 - 46, 12, 20, 10, 13, 9, 12, 8, 6, 4
- Equal number of shots to each target (Even)
 - Player 1 - 13, 12, 13, 12,...
 - Player 2 - 16, 15, 16,...
 - Player 3 - 19, 9,...

- Improvement sequences of consistent pattern (Con)

- Player 1 - 5, 10, 5, 10,...
- Player 2 - 5, 10, 5, 10,...
- Player 3 - 20, 20, 20, 20,...

The decreasing number of shot per sequence follows a logic that offer more time to recuperate following a higher sequence of shots to Target B as well as over all drill fatigue. Equal number of shots creates a low shot count per sequence thus aiming to reduce fatigue accumulation in the drill (this is based on the average number of shots observed in the game for each player). In our last attempt we examine sequences the seems to produce a higher score.

In Table 4.8, the changes to the game score with the three players is demonstrated when applying the new decision patterns. The second pattern of equal number of shots performed worst while the consistent pattern performed the best. When tested statistically (30 replication per simulation run and using ANOVA for comparing means), there was a difference in the game scores among the decision patterns for the players one and two (P-value = 0.000, P-value = 0.000), and no difference for player three (P-value = 0.337).

Table 4.8: Decision pattern testing results

Player	Original	Org	Even	Con
Player 1	161	161	157	179
Player 2	188	192	189	205
Player 3	249	249	244	252

In order to find the best decision-making pattern to improve each players performance we apply OptQuest in the next section and demonstrate its results.

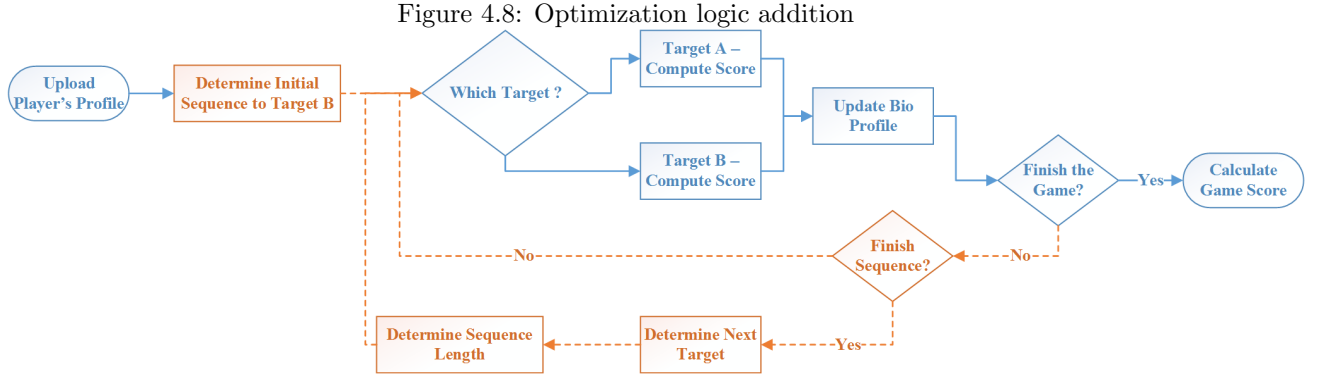
4.6.5 Optimizing decisions making under fatigue - model 2

As stated previously, due to the impact of fatigue, sequence of shots to Target B will reduce the player level of performance upon reaching certain physical condition (heart rate). A sequence of shots to Target A will help the player to recuperate and return to the earlier performance level.

The common problem with this scenario depends on the payer awareness of his physiological state (heart rate in this case). If the player detects immediately that he moved to a lower performance level, he can adjust his shot selection and better maintain an overall performance level (allowing for recuperation while still scoring on the easier target). If a delay occurs in the player's awareness of his physiological

conditions, it will require more time to return to his earlier level of success and, as a result, will decrease overall performance.

In order to determine the best decision-making pattern for each player, additional logic is added to the simulation model. Utilizing OptQuest (and new decision variables in the simulation model), we ask the model to find the best sequence setup when alternating between targets, with the objective of maximizing the player score (see Figure 4.9). In this scheme, all player profile characteristics remains the same (e.g. probability of success, heart rate trends, and physiological thresholds).

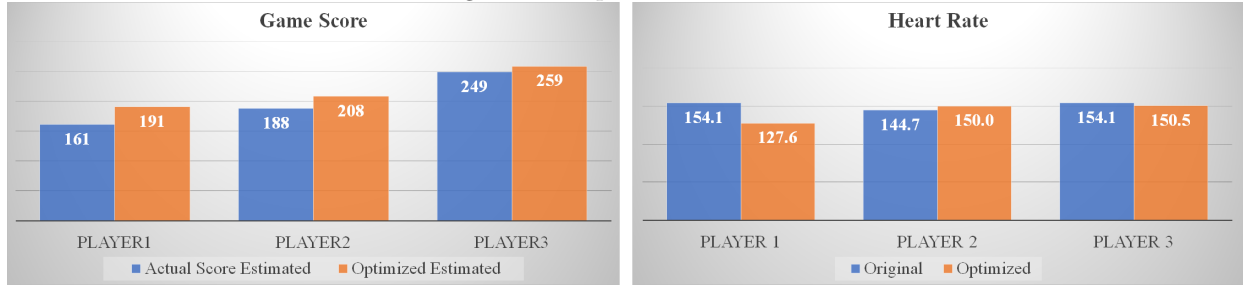


As demonstrated in Figure 4.8, the decision for the next sequence is made the former sequence is completed, thus the model mimics the logic of the player in terms of how decisions are made and when do they take place. Moreover, the model takes into consideration the expected performance over the sequence, knowing what will happen to the heart rate level of the player and how performance may change accordingly.

In Figure 4.10, we can see the optimization results for the long run estimated performance. The expected average game score is compared between the actual score achieved and the optimization estimation. As demonstrated, the players will improve their performance by 18%, 11%, and 4% with statistical significance (P -value = 0.000, 0.000, 0.002 for player one, two and three). The three players represent different skill levels, and as projected, player one (amateur level) has a higher improvement potential than player three (professional) when adjusting their decision-making patterns. The optimized decision pattern also impacted the average heart rate of the player during the game. In general, a heart rate reduction on average among players is expected, however, there are some players that will reflect differently. For example, player two will perform better at a higher level of average heart rate in the game. It can also be an early indication that his awareness for recuperating (when to hit again to Target B) is lower than it should be, thus he is taking more time (in a sequence of shots to target A) than he needed.

Although there is an improvement in the game score, further analysis is required in order to under-

Figure 4.9: Optimization results



stand the causes for this improvement. When looking at the decision-making pattern and shot distribution, it can be illustrated that under certain physiological conditions the players perform better. In Table 4.9, the decision-making pattern of the players is demonstrated as well as a breakdown of the physiological conditions (heart rate threshold) as a result of the selected decision-making pattern. The comparison between the player's original pattern and the optimized pattern, is demonstrated here as well.

When looking at player 1 decision-making pattern, we can see that his original plan included 12 transitions between targets. The player difference in shot count between targets is nine shots in favor of Target A (66 shots to Target B, 75 to Target A). This decision-making pattern resulted in performing 87 shots in the high threshold, 45 shots in the medium threshold and nine shots in the low threshold. The optimization created a significant change in the decision-making pattern. The transitions between targets are reduces to four. The difference in shot count between targets increased to 75 (108 shots to Target A and 33 shots to Target B). The optimized pattern resulted in performing zero shots in the high threshold, 73 shots in the medium threshold and 68 shots in the low threshold. Similar changes in decision-making patterns can be seen for players two and three in Table 4.9.

Table 4.9: Comparison between decision-making patterns

Player	# Transitions	Target A	Target B	Low	Med	High
Player 1 - Original	12	75	66	9	45	87
Player 1 - Optimized	4	108	33	68	73	0
Player 2 - Original	8	66	75	85	23	33
Player 2 - Optimized	4	97	44	136	3	2
Player 3 - Original	9	44	97	6	62	73
Player 3 - Optimized	4	67	74	6	121	14

When comparing the original and the optimize pattern, better score will be achieved by reducing the number of transitions, increasing the number of shots to Target A, and reducing the number of shots to Target B. These changes will result in the player performing at a lower heart rate threshold thus increasing

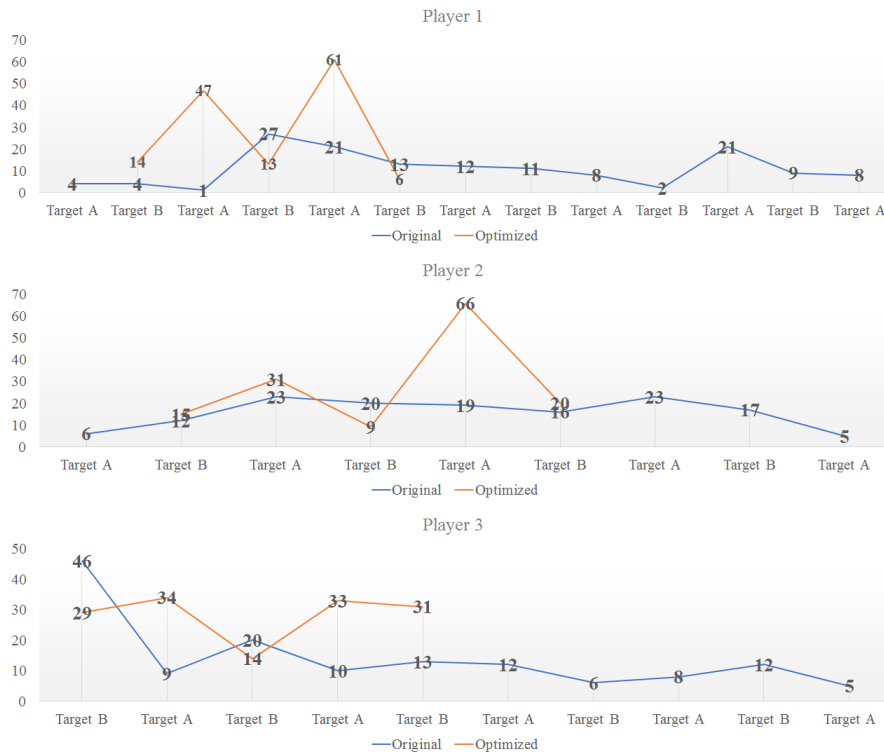
his probability of successfully hitting the target. In Figure 4.10, the sequences breakdown is presented when comparing the original pattern to the optimized one. The graphs shows how the optimize pattern is more concise and focus and represent the necessary recuperation time (number of shots to Target A).

When making a policy that will guide players in dealing with fatigue, we recommend taking under consideration the following parameters:

- The average number of shots per sequence for Target B
- The ratio of shots between targets to achieve adequate recuperation

The average number of shots for Target B will reflect the ability of the player to perform under the best physiological condition based in heart rate in this case. We can see that on average player one and two average 13 and 16 shots for Target B, while player three averaged 27 shots for Target B (when considering the optimized sequence). This indicates that player three can produce adequate performance under higher levels of fatigue than players one and two (due to the sequence length).

Figure 4.10: Optimization sequencing results



When considering the number of shots to Target A for recuperation, we can see that player one and two will average 49 shots, while player three will average 33 shots. This means that player three recuperate

faster thus explain the advantage over player one and two.

4.7 Discussion

The ability to determine the best level of performance based on physiological conditions is of great value to athletes. When fatigue settles in, performance capability changes and this often leads to a change in the decision pattern. In practice, the ability to teach the player to tune his decisions to his physiological condition can make a critical difference in performance. In competition, the ability to alert the player to his physical state will help guide the player to a better strategic and tactical choices in the game. In tennis specifically, winning a grand slam will require eight consecutive wins over matches that can take between three to five sets each. The conservation of energy is important in these settings, as the level of fatigue will impact the physiological, psychological and emotional state of the player.

Our research represents only one parameter in this sophisticated environment, thus this framework can aid the calibration and testing of additional variables like, stress, awareness, intuition and more. The utilization of simulation can foster a higher level of complexity between the decision-making logic, the state in which a decision is made and dynamics that arise from the game scenario. This research area will require more technological innovation to capture such data, and an high level of processing capability to streamline this into a practical application in real time.

4.8 Conclusions

This research provides support to existing literature on how fatigue accumulation affects tennis player performance. There are many challenges when considering the cause and effect relationships of performance characteristics. This study presented a framework for analyzing and improving performance under fatigue specifically in the designed game. decision-making patterns could be tested with various logical settings as well as in different game scenarios. The potential application of this research is to establish an interactive tool for players and coaches to learn from, in training and in competition. With innovative technologies more information can be drawn about the players physiological, psychological and emotional conditions in order to generate better training mechanisms and real time indicators of performance. The utilization of the simulation and optimization modeling could be further developed to include a higher level of complexity and deliver a variety of alternatives based on the player's style of play.

4.9 Acknowledgments

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4.11 Appendix

Optimization notation based on the simulation parameters

$$\text{maximize } GS$$

$$\text{subject to } Th_i = T_i, \ i = 1, \dots, n.$$

$$Tp_jk = P_jk, \ j = 1, k = 1, \dots, m, l.$$

$$L_d \leq Tr_d \leq U_d, \ d = 1, \dots, D.$$

$$vLT_{(HRA)} \geq vMT_{(HRA)} \geq vHT_{(HRA)}$$

$$vLT_{(HRB)} \geq vMT_{(HRB)} \geq vHT_{(HRB)}$$

$$GS \leq RS$$

Chapter 5

Conclusions and Discussion

In this final section of the dissertation, I will address the lessons that I have learned throughout this research project as well as the overall research development and future implications. The initial section will address the research questions that guided this work which will be followed by my contribution to sports management and performance. Next I will discuss the key skills and knowledge that I gained throughout this project and how they have shaped my professional approach as a researcher. Lastly, I will address future endeavors that I will pursue in my career.

5.1 Main Research Findings

The research questions that guided this research came from a collaboration between engineers, players, coaches, sports managers and athletic program directors.

In chapter two, the work illustrates how to classify human performance characteristics, as they affect a player's perception, decision making and execution capabilities. Moreover, we presented both direct impact relationships (first level) and indirect impact (successive levels) relationships. The impact of the performance characteristics was determined from a top to bottom framework as described in detail in the chapter. The knowledge gained through this engagement resulted in an integration of performance characteristics assessment within the tennis training program, led by the former Clemson athletic director Bill D'Andrea. Our findings indicated that some features of performance reside deep within the character of the player, and in order to make a change at that level, much effort is required. Recruiting is a critical element of success, and program management realized that the recruitment process should include determining if potential players

have a baseline performance level that fits the coaches' training style as well as the needs of the program (from a player decision making and characteristics point-of-view).

Led by insights from chapter two, chapter three focused on comparing a player's performance characteristics to that of an opponent, the resulting decisions to be made on style of play, and how this approach can help match the coach's expectation with the player's performance capability. The recruiting process for college level players has specific guidelines that serve to protect the player, the coaches and the athletic program. From literature research, data collection and interviews with professional coaches and managers in different fields, we observed a lack of focus on the decision making nature of the player. Since physical assessments are necessary and provided by the player, physical capabilities are easily determined and pose no challenge to the recruiting process. The physical requirements are translated directly to numbers on a screening mechanism for performance evaluation, but it is his decision making nature that is often a determining factor of performance. With this in mind, the work in this chapter provided a framework that could be used to determine the player decision making style while he is going through the recruiting process. A player that fits the recruiting position criteria from the physical and logical perspectives will fulfill the coach's expectation, thus will prove to be a match to that position in the program. Although the framework contained a solid mathematical background, its practical application should be customized to the specific recruiting process in order to be effectively implemented.

We then focused on examining the connection between chapter two and chapter three. In order to understand how performance characteristics impact decision making we created a game that challenged decision making logic under conditions of fatigue. Designed to improve the tennis player performance, the game presented a scenario of high risk and high reward target selection as well as low risk and low reward target selection, where player performance (the ability to hit the targets) degrades over time. The findings supported existing literature when considering performance changes over time. Moreover, we illustrated how a change in the decision making pattern, can improve the overall player performance in the game. This work addressed one of the key elements of human performance which is the awareness of performance under certain physiological conditions. Managing shot selection (i.e., decision making patterns) more effectively allowed a player to achieve higher game scores in spite of reduced physical ability (i.e., fatigue).

5.2 Research contributions

Each chapter in this work presents an area of contribution, some more practical than others. In chapter two, my contribution can be illustrated in many aspects. At first, the integration of an engineer into

an athletic program is unique. The athletic director Bill D'Andrea saw this as an opportunity to promote analytics within various athletic programs. Specifically in the woman tennis program, the tennis program expanded their resources and involved more people in their management procedures, including a specialized physical trainer, nutritionist, academic adviser and an industrial engineer. The practice changed from a group development to personal development. The competition preparation was embedded in various aspects of the practice, which promoted a high level of readiness at all times as well as continuous improvement of performance under conditions of uncertainty. The research allowed the program to understand the inner world of the player and the various factors that dictate the players performance. The research engagement allowed the tennis coaches to have confidence as results were analyze and prediction put in place when testing their training strategies. In this research engagement we noticed changes in players due to the implementation of the SDI methodology. Players, coaches and managers were challenged when asked to assess factors of influence beyond the direct cause and effect relationship. In each encounter, we noticed that by asking iterative questions to get root causes, people started to think outside of the box. In the first month of the research, players provided answers, mainly revolving around their own setting (how they feel, how much energy they have, if they are out of focus from studying to much or just tired from over practicing), coaches provided answers, revolving around program settings (practice hours, how many drills they run, etc.) and management provided perspectives based on individual player accomplishments and team accomplishment. During the later months the answers started to change as the framework helped them realize how elements of player capabilities were connected at each level within a player and across players to the team concept. As I was working along side of the coaching staff, I felt as if we have all learned a new language; we were excited to see how our results had change as each course of action had a fundamental reasoning that was not there before.

We then chose to focus on the recruiting process as it became evident that it is a critical element of success. When we discussed with the coaching staff the idea of testing a player decision making logic they began to question why they didn't have this already embedded in their recruiting process. With much excitement, we soon realized that there is a gap in this area, thus the opportunity of contributing to the tennis program as well as to various athletic recruiting programs, presented it self. In this work, we have provided a mathematical settings using decision trees, to identify the best player response in a given scenario. The analysis is taking under consideration the relative advantage of specific performance characteristics, when evaluating strategies and tactics in a given situation. This work have provided a method that allows recruiters (coaches) to design a scenario so that each decision alternative reveals information about the player's decision

making style and as a result, improving the recruiting process by including the decision making nature to the physical profile when evaluating a potential recruit.

In chapter four, we created a model that provided insights into how a player can manage performance under fatigue. The method included a baseline drill, a game and a simulation model. Players that participated in this study helped establish decision making patterns that validated the drill design, and they learned about the impact of fatigue on their performance. The Clemson University creative inquiry research group helped run portions of the experiment , it helped open another area for undergraduate engineers as they had a hands-on learning experience outside of the classroom. The research demonstrated how decision making can be improved when considering the impact of fatigue on the player performance. In particular, simulation was used to model the combination of target selection, heart rate, and fatigue over a series of consecutive shots taken without rest. For a particular player profile, different shot selection patterns can be tested in an effort to maximize player score, which is affected by a reduction in success rate of hitting the targets as the player gets tired (i.e., heart rate increases). The model not only demonstrated these changes in the form of a predicted score of the game but can also suggest a decision making pattern that would lead to better results over time by simultaneously managing fatigue and shot selection.

Throughout my research and time spent here in Clemson University, I have worked diligently to promote undergraduate research, innovative technology and student mentorship. Leading a research group in this dissertation was a great experience and our contribution is valuable to the Clemson Undergraduate Creative Inquiry Program. As a group, presenting findings of this dissertation, we have presented in conferences and submitted papers to publication in the field of human performance. Due to this contribution I received an award for mentorship in April 2017.

5.3 Shaping my professional approach

This research presented in the dissertation is multidisciplinary, and requires input and guidance from various specialists. It is a hands-on research where data needed to be collected, experiments needed to be coordinated and approval was needed to be achieved for conducting human trials. It presented innovative spirit and dealt with various challenges. Motivated to include a vast and rich data set while addressing high level of complexity, I have learned to structure this research under the allowable time and available resources in my degree program. Knowing your limitation as a researcher will be of great value, especially when considering future grant proposals.

Working with tennis players, coaches and directors, I learned that different job responsibilities

generate different perceptions. In order to improve a system that present this complexity, the first thing to do it to determine a common language. In addition, I have learned that making real changes takes time and effort beyond what is expected. In order to effectively make changes, people needs to be involved in a way that influence "out of the box" line of thinking. In order to convince people that change is a good thing, scientific evidence needs to be presented. People will accept change more intuitively if it is based on facts rather than estimation or feelings. Motivation and excitement is key to improvement process as well as harnessing the leverage of a managerial position (promotes the willingness to participate).

Working with undergraduate students have taught me how to connect with students of different backgrounds and create a group effort for completing a project. I have learned how to motivate students and help each one in their own way to achieve his goals. Most importantly, I have learned how much I can learn from them, as they are curious, full with new ideas, and questions that I surprise me every time. I cherish this engagement and hope to continue developing it wherever I go.

Mentored by my adviser, the experience has truly shaped my research approach. Dr. Kevin Taaffe was enabling me to experience research in a way that was quit unique. I was able to work under his guides while researching an area that is not traditional to our discipline, and it feels like we only scratch the surface of what we can accomplish together. I have learned from him that research takes time and that focus is key. Differently from my personality trait of innovating and creating new ideas, research needs to be very constructed and focus. I have learned that it is very beneficial to reach out and consult with specialist, friends and colleagues, as that feedback is always positive in its own way. I have learned that working with people takes patience and diligence as I watched him lead our collaboration with various departments on campus. Lastly, Perhaps the most important lesson that I learned from my mentor is to be a man of value and character, especially when life challenges arises. He had always treated me with a sense of care and kindness throughout my time here at Clemson, especially when dealing with a student who is challenged by a reading disorder and dyslexia.

5.4 Future endeavors

My experience at Clemson created various opportunities for research collaborations. Humans are the most complex systems in the world and demonstrate multilevel dynamic structure that involve knowledge from all disciplines that currently exist. Understanding features of this complex system will be my career path as it is embedded in me to pursue it. In order to investigate this area, I need to learn more about the human biology, anatomy, circuitry and functionality. With this in mind, an opportunity had presented

itself in the health field. With the submission of this dissertation, I will assume a post-doctoral position with the emergency medicine department in Greenville Memorial Hospital. This experience will allow me to expand my understanding of human performance from a medical point of view as well as allow me to aid the emergency department with various process improvement projects. It intend to promote my relationships here at Clemson as they will be forever part of my life.